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Evaluation of Random and Indexing Sampling Designs for Estimating Coho Salmon (*Oncorhynchus kisutch*) Escapement to Three Vancouver Island Streams

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EVALUATION OF RANDOM AND INDEXING
SAMPLING DESIGNS FOR ESTIMATING COHO
SALMON (Oncorhynchus kisutch) ESCAPEMENT
TO THREE VANCOUVER ISLAND STREAMS

by

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ABSTRACT

Bocking, R. C., J. R. Irvine, K. K. English, and M. Labelle. 1988.
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salmon (Oncorhynchus kisutch) escapement to three Vancouver Island
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Results are given for the second year of a research program evaluating instream escapement indexing in which counts of coho salmon (Oncorhynchus kisutch) in certain segments of a stream are used as indicators of the abundance of salmon in the entire stream. We evaluated the accuracy and precision of escapement estimates generated for three Vancouver Island streams, French Creek, Black Creek, and Trent River. Counts of coho were obtained in French and Black creeks by a two-man crew walking through survey areas. In the Trent River, a diver floated the river while a second person accompanied him on foot. For each system we investigated several sampling designs: simple random sampling, stratified random sampling, index sampling, and stratified index sampling. We assessed the effect of the amount of survey effort, the efficiency of observing coho using foot surveys, and the value of coho survey life on resulting escapement estimates. Data were obtained for the Trent River for the entire region of the river accessible to coho, hence computer simulations were used to evaluate differences between various sampling regimes. For each stream, mark-recapture estimates of escapement were available to compare with our escapement estimates. Between 35 and 54 percent of the adult coho captured by an electrofishing crew were seen by observers conducting visual surveys. The efficiency of observing jacks was 57 percent of the efficiency of observing adult coho. Counts of adult coho at randomly selected sites produced escapement estimates between 19 and 150 percent of mark-recapture estimates while counts at index sites produced estimates ranging from 65 to 255 percent. Escapement estimates derived from counts at index sites were generally more precise than counts at random sites. Different approaches were appropriate for the different streams. In Black Creek, where coho seemed to congregate in large spawning areas, numerous relatively small sample sites produced reasonably accurate and precise escapement estimates. On the other hand, for French Creek and the Trent River, where coho were more sparsely distributed and aggregated in small habitat units, it was better to direct survey efforts into patrolling longer survey units. On average, surveys of 12 index sites, each 250 m long, were sufficient to produce reliable indices of escapement. For some streams, systematic surveys of estuary sites may be the most cost effective way of producing reliable and consistent indices of coho escapement. Determining the relationship between numbers of fish in index areas and escapement, and whether this relationship remains constant in years with different escapement levels, will require a longer time series of data than is currently available. We conclude that although the estimation of coho escapement to streams in B.C. is a difficult task, it appears that it is feasible to obtain escapement estimates with reasonable accuracy and precision by conducting visual instream surveys.

RÉSUMÉ

Bocking, R. C., J. R. Irvine, K. K. English, and M. Labelle. 1988.
Evaluation of random and indexing sampling designs for estimating coho salmon (Oncorhynchus kisutch) escapement to three Vancouver Island streams. Can. Tech. Rep. Fish. Aquat. Sci. 1639: 95 p.

Ce rapport donne les résultats obtenus au cours de la deuxième année d'un programme de recherche visant à évaluer l'indexation des échappées dans les cours d'eau dans lequel les dénombrements de saumons coho (Oncorhynchus kisutch) dans certains segments d'un cours d'eau servent d'indicateurs de l'abondance du saumon dans tout le cours d'eau en question. L'exactitude et la précision des estimations des échappées pour trois cours d'eau de l'île de Vancouver, le ruisseau French, le ruisseau Black et la rivière Trent, ont été évaluées. Les dénombrements de coho ont été effectués dans les ruisseaux French et Black par une équipe de deux hommes qui ont parcouru à pied la zone du dénombrement. Dans la rivière Trent, un plongeur a parcouru la rivière tandis qu'une deuxième personne l'accompagnait à pied. Pour chaque système, plusieurs plans d'échantillonnage ont été étudiés: l'échantillonnage aléatoire simple, l'échantillonnage aléatoire stratifié, l'échantillonnage par incide et l'échantillonnage par indice stratifié. L'effet de la quantité d'effort des relevés et de l'efficacité des observations effectuées à pied sur les estimations des échappées qui en résultent ont été évaluées. Des données ont été obtenues pour toute la section de la rivière Trent accessible aux coho et c'est pourquoi des simulations sur ordinateur ont été utilisées pour évaluer les différences entre les divers régimes d'échantillonnage. Pour chaque cours d'eau, on possédait des estimations de marquage-recapture pour les échappées pour les comparer aux nouvelles données d'échappées obtenues. Entre 35 et 54 % des coho adultes capturés par une équipe de pêche électrique ont été aperçus par des observateurs effectuant des levés visuels. L'efficacité de l'observation des jacks s'élevait à 57 % de celle de l'observation des poissons adultes. Les dénombrements de coho adultes dans des lieux choisis au hasard ont donné des estimations d'échappées variant entre 19 et 150 % des estimations établies par marquage-recapture, tandis que les dénombrements dans les lieux indices ont donné des estimations variant de 65 à 255%. Des estimations des échappées dérivées des dénombrements dans les sites indices étaient généralement plus précises que les dénombrements dans les sites choisis au hasard. Des approches différentes convenaient pour les différents cours d'eau. Dans le ruisseau Black, où le coho semble se rassembler dans de vastes zones de fraie, l'emploi de nombreux sites d'échantillonnage relativement petits a donné des estimations raisonnablement exactes et précises de l'échappée. Par ailleurs, dans le ruisseau French et la rivière Trent, où la distribution du coho est plus éparse et où les poissons se rassemblent en plus petites unités d'habitats, il était préférable d'orienter les efforts de dénombrement en fonction d'unités de dénombrement plus longues. En moyenne, les dénombrements effectués dans 12 sites indices de 250 m de longueur chacun ont suffi à produire des indices viables de l'échappée. Dans certains cours d'eau, des levés systématiques des sites estuariens pourraient s'avérer la méthode la plus rentable pour obtenir des

indices fiables et constants de l'échappée des coho. Il faudrait obtenir de plus longues séries chronologiques de données que celles qui existent à l'heure actuelle pour déterminer le rapport entre le nombre de poissons dans les sites indices et l'échappée et pour déterminer si ce rapport demeure constant au cours des années compte tenu de niveaux d'échappée du coho dans les cours d'eau de la Colombie-Britannique soit une tâche difficile, il semble possible d'établir des estimations raisonnablement exactes et précises en effectuant des dénombrements visuels dans les cours d'eau.

INTRODUCTION

Increasing fishery and environmental pressures exerted upon our salmon resources have correspondingly increased the need for accurate and precise information on stock status. Since there are large numbers of salmon populations, and it is impractical to monitor each on a continuing basis, it has become necessary to develop accurate and cost-effective methods of stock assessment. Escapement estimates by fishery officers and stream guardians (Cousens et al. 1982) are frequently used as indicators of stock status. These estimates are usually based on field observations conducted in parts of each river, combined with a subjective assessment of the proportion of the whole population observed. A lack of standard procedures has precluded a systematic evaluation of these estimation procedures. Consequently, most escapement estimates are considered unreliable, and represent only a rough indicator of temporal trends in escapement. Nevertheless, there is an incentive to improve the estimation procedure rather than implementing a totally new stock assessment program (Wong et al. 1985).

In 1986 a research program was initiated at French Creek (Fig. 1) to evaluate instream escapement indexing for coho salmon (*Oncorhynchus kisutch*) in which counts of salmon in certain segments of a stream are used as indicators of the abundance of salmon in the entire stream (Johnston et al. 1987). In 1987 we expanded this program to include the Trent River and Black Creek for which fence counts and mark-recapture estimates of coho salmon escapement are also available.

Measurement errors in escapement estimates can have a profound effect on stock/recruitment estimates (Walters and Ludwig 1981). Random errors in escapement estimates tend to dampen the stock-recruitment curve and result in the underestimation of optimum escapement requirements (Walters 1984). This can result in substantial losses in the average long-term yield from a stock. Bias in escapement estimation is not as serious a problem (Symons and Waldichuk 1984, p. 17). If the escapement estimation method gives a precise fractional count of the true escapement each year, then it may be a good tool for measuring seasonal trends, relative responses to management actions, and reflecting changes in the biological environment (Walters 1984). Furthermore, if the relationship between fractional counts of escapement and true escapements can be determined from a time series of data, then stock/recruitment relationships can be refined. Improving traditional escapement estimation procedures to reduce random and systematic errors will eventually increase the ability of fishery managers to assess the condition of salmon stocks.

Estimation of the number of fish in a stream at one point in time may be achieved through the use of a multistage sampling design (Hankin 1984, Hankin and Reeves 1988). Cochran (1977) presents the statistical basis for multistage sampling. At the first stage, a sample of stream sections is selected, while at the second stage, the total number of fish present in each section is estimated. Uncertainty is introduced at both stages of sampling. The selection of stream units introduces uncertainty in the population estimate, and at the second stage, the efficiency with which the observation method enumerates fish introduces uncertainty. A properly designed escapement enumeration system should attempt to minimize uncertainty at both stages. So

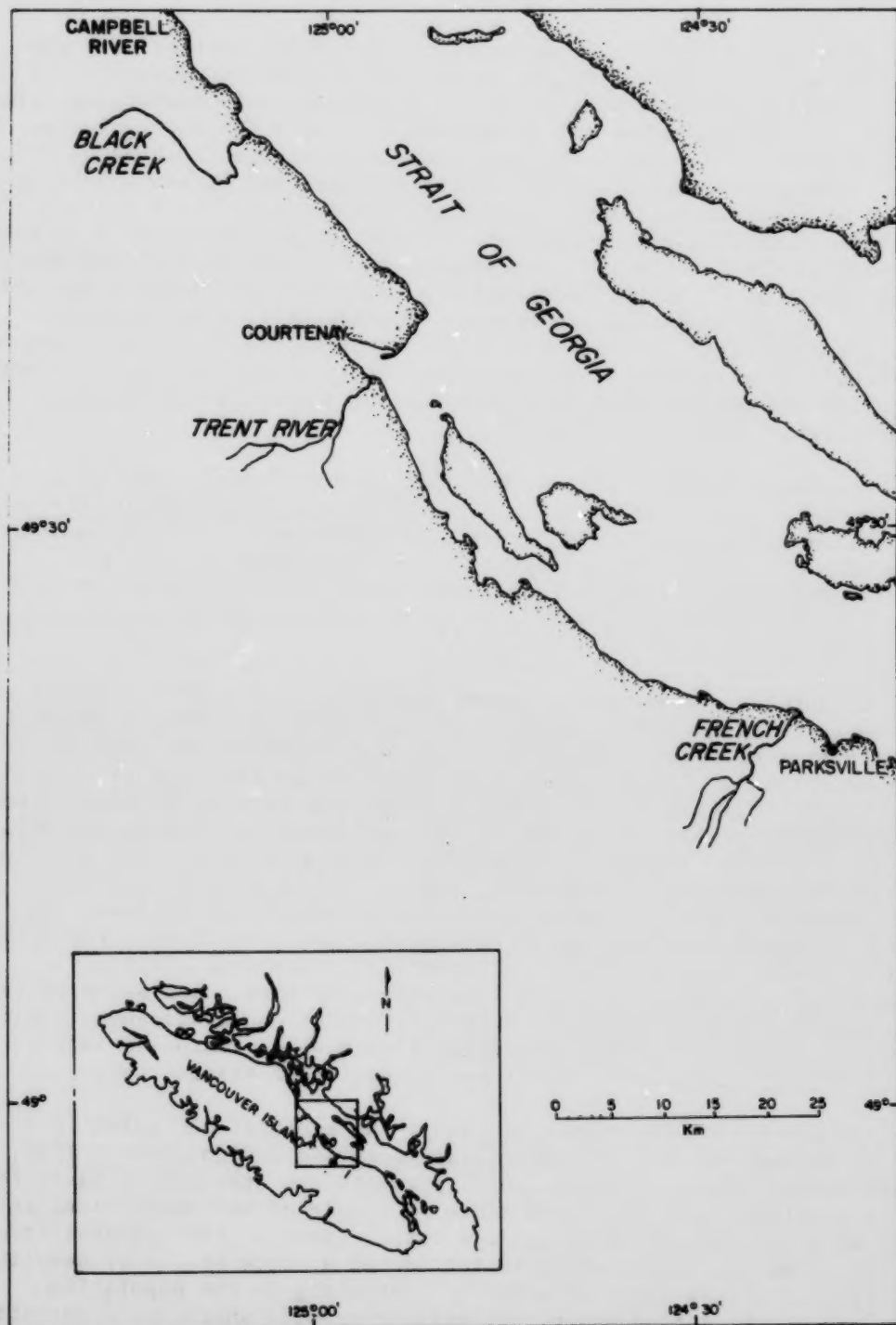


Fig. 1. Map of Vancouver Island showing location of study streams.

far, little attention has been focused on the applicability of appropriate sampling methods for conducting escapement enumeration.

With respect to the first stage of sampling, fish census locations have been traditionally determined by accessibility and the time available to make observations (Ames 1984). Recently, attempts have been made to conduct observations at various locations according to a pre-determined random or systematic design (Johnston et al. 1987). Many statistical methods require that samples be taken randomly to eliminate bias, and to ensure that they are representative of the entire population. However, as pointed out by Cochran (1977), other methods of sampling are sometimes preferable to simple random sampling on the basis of convenience or increased precision. Elliott (1977) noted that all the randomly selected units in a sample may fall in one part of the sampling area, particularly when only a small portion of the total population is sampled. Hurlbert (1984) concluded that interspersing of sample units reduces bias and thus, is often a more practical criterion than is randomization. If interspersing is used, then it is necessary to find a way of interspersing the sample units according to a systematic procedure while remaining unbiased. For a stream that is not totally accessible, this requires identifying the accessible portions of the river, and then determining a set of units within the accessible portions which are equidistant. This is analogous to geographical stratification (Cochran 1977).

As noted by Cochran (1977) and Elliott (1977), stratification can increase precision while minimizing bias in the estimates of a population's characteristics by ensuring that the population subdivisions are adequately represented. A stratified random sampling design is achieved by stratifying the population and then randomly selecting sample sites within each stratum. Elliott (1977) suggests that in some situations this design is more statistically correct than simple random sampling. Stratification might be particularly appropriate for salmon streams, where the distribution of fish can be highly aggregated. Cochran (1977) also noted that the ideal variant for stratification is the variable one is attempting to estimate (in our case, adult coho density). However, Cochran (1977) pointed out that in practice this type of stratification is usually impossible to achieve.

The amount of uncertainty introduced at the first stage of sampling also depends, in part, on the level of sampling effort, specifically: 1) the number of sample units surveyed; 2) the size of each sample unit; and 3) the frequency of sampling during the course of the escapement run. In determining sample unit size, the usual approach is to cover as much area as possible in as many accessible locations as possible. The number, size, and frequency of surveys are invariably influenced by logistical constraints and, therefore, sampling is usually less than ideal.

Johnston et al. (1987) systematically evaluated the effect of survey unit size (i.e., length of stream surveyed) on the precision and accuracy of coho escapement estimates. In French Creek they found that visual foot surveys of stream sections that were 200 and 400 m provided similar population estimates in terms of precision, and were preferable to surveys of 100 m sections. However, the investigators did not determine the ideal stream lengths to be surveyed based on the relative degree of precision obtained by each method. We are not aware of any study that compares the accuracy or precision of escapement estimates using different numbers of sample units.

The main source of error at the second stage of sampling (estimating total number of fish per section) arises from the inefficiency of visual foot surveys to count coho. Solazzi (1984) determined that surveyors observed approximately 75% of the adult coho, and 50% of the jacks present in various stream sections. Similar results were obtained by Johnston et al. (1987). Shardlow et al. (1987) determined that species, observation method, stream attributes, and observer experience influenced salmon abundance estimates in the Big Qualicum River on the east coast of Vancouver Island. In British Columbia, it is usually left to the fishery officers conducting escapement enumerations to estimate their own foot survey efficiency. Methods are seldom rigorous and may be undocumented.

Additional sources of variation in escapement estimates may arise depending on the method used to obtain the estimate. One method sometimes used is to repeatedly count the number of fish in a survey area and divide the total number of fish days (area under the escapement curve) by the average length of time fish spend in the study area. When the area under the curve (AUC) method is used, there are two major sources of error: 1) error associated with the estimate of the area under the curve (number of live fish-days for the entire spawning season); and 2) the error associated with the estimate of the average number of days each spawner is alive in the survey area.

The average life-span of fish in the survey area (survey life) can be interpreted and calculated in different ways depending on how the survey area is defined (Perrin and Irvine 1988). In turn, the definition of the survey area is dependent on the sampling methods used and the method used to expand fish counts to a population estimate. For example, if the survey area is considered to be the entire stream and one wishes to estimate the entire stream population, then survey life should be the average number of days that fish spend alive in the stream. This has been commonly referred to as stream life or freshwater residence time (Ames 1984; Neilson and Geen 1981). Alternatively, if spawning ground counts are being used to estimate the number of spawners, then the average number of days that fish spend alive on the spawning ground (spawning ground life) should be used. The different measures of survey life are highly variable. The time spent alive in the stream (stream life) varies with species of salmon, sex, stock, and year (Ames 1984; Neilson and Geen 1981). Newman (1984) pointed out that redd life which has been used to estimate spawning ground life is also highly variable.

Since survey life is a key component in the use of the AUC method, the survey life must be known for each stock and year, at least until there is a better understanding of the causes of variations in survey life (Perrin and Irvine 1988). An alternative method of determining escapement estimates using the AUC is to compare the AUC estimate for the number of fish-days to some base year index (Flint 1984). As Flint noted, selection of a particular base year can also have a significant effect on the resulting estimates. Few empirical investigations have been done to evaluate the uncertainties associated with calculating survey life of adult coho or the use of base year indices.

Until recently, peak counts from index areas of Washington coho systems were used to obtain a relative measure of spawning escapement among years (Zillges 1977). However, recent studies in Washington (Ames 1984, Flint 1983) prompted the Washington Department of Fisheries to use the AUC method. In 1984, Flint provided further evidence suggesting the AUC method was not as

reliable as previously thought. His comparison of coho indexing methods revealed that peak live counts were less variable than counts using the AUC method.

In this study we evaluated the precision and accuracy of indices of abundance and estimates of escapement obtained from visual counts using different sampling designs (index sampling, random sampling, and stratified sampling), levels of sampling effort (survey unit size and number), and methods of calculation (AUC and peak live). We compared estimates of escapements using visual foot surveys with independent estimates obtained using adult fish fence counts and mark-recapture estimates. We also evaluated the effects of the efficiency of visual foot surveys and survey life, two key components in the expansion of visual counts to indices of abundance or escapement population estimates. Our specific objectives were:

1. To determine which of the following sampling designs produced the most reliable and accurate escapement estimates: simple random sampling, stratified random sampling, index sampling, and stratified index sampling.
2. To determine the optimum number and size of survey sites.
3. To evaluate the effect of observer efficiency on escapement estimates.
4. To evaluate the effect of survey life on AUC escapement estimates.
5. To compare the results from the first 4 objectives for three different coho streams on Vancouver Island.

By comparing our results for French Creek with those of the previous study of 1986 in this system (Johnston et al. 1987), we also attempted to derive a preliminary understanding of the following long-term objectives:

6. To determine the relationship (if any) between the numbers of fish in arbitrarily chosen index areas and the actual escapement.
7. To assess whether this relationship is the same in different years with different escapement levels.
8. To investigate whether population estimates in these areas can be used as reliable indices of total escapement.

MATERIALS AND METHODS

STUDY STREAMS

Black Creek is a small stream on the east coast of Vancouver Island, approximately 30 km north of Courtenay (Fig. 1). The physical and biological characteristics of the system have been described by Hamilton (1978), Hancock and Marshall (1985) and Labelle (in prep), from which the following information was obtained.

The creek is 26 km long, and approximately 5-6 m wide at midsection. The headwaters are in the higher elevations of Mount Washington, and the stream flows in a northeasterly direction to Elma Bay, in the Strait of Georgia. The intertidal section is narrow, short (<0.5 km), and relatively flat with sand and mud substrates. The creek varies from a steep gradient mountain stream at higher elevations, to a sluggish meandering stream flowing through agricultural land and swamps, with dense overgrowth of vegetation in its lower elevation. In the lower reaches, the creek includes many lakes, swampy depressions, beaver ponds and several tributaries including Millar Creek and Sayer Creek (Fig. 2). Bank erosion, undercutting, scouring and silting occur to some extent in the lower sections but are absent along most of the middle and upper reaches. The streambed is composed mostly of a mixture of sand, silt and clay. Peak discharge is known to reach at least 30 m³/s during fall and winter floods. During summer, stream flow may decrease to negligible levels and cause some sections in the lower reaches to be completely dry.

For its size, Black Creek is an exceptionally good coho producer. During the past 10 years, escapements have been reported to reach 8,400 coho, but fishery officers reported up to 16,000 fish prior to 1975 (Hancock and Marshall 1985). Hamilton (1978) and Labelle (in prep) noted that upstream migration of coho in Black Creek is governed by the arrival of fall rains. In some years, insufficient flow at the stream mouth delays upstream migration, inducing substantial fish mortality in tidewaters, and preventing access to spawning locations (Hamilton 1978). Hamilton (1978) and Labelle (in prep) documented that upstream migration could begin as early as 3 October, and as late as 18 November. Labelle (in prep) observed that peak upmigration in 1985 and 1986 occurred around the third week of October and November respectively. However, upstream movement during both seasons was affected by severe weather anomalies (freeze-up in 1985, drought in 1986), and thus may be atypical. Labelle (in prep) found that over 80% of all adults moved upstream during the first week of upmigration in 1985 and 1986.

During 1985 and 1986, most spawning occurred between late November and mid-December (Labelle in prep). Coho spawned throughout the creek, but the best spawning grounds were in Millar Creek, in mainstem areas adjacent to the Kelland and Sturgess road bridges, and in the upper reaches above the junction of the Duncan Main logging road (Fig. 2).

Trent River is a medium size stream on the eastern side of Vancouver Island, entering the Strait of Georgia near Royston, south of Courtenay (Fig. 1). The river's source is in the Beaufort Range, and it flows in a

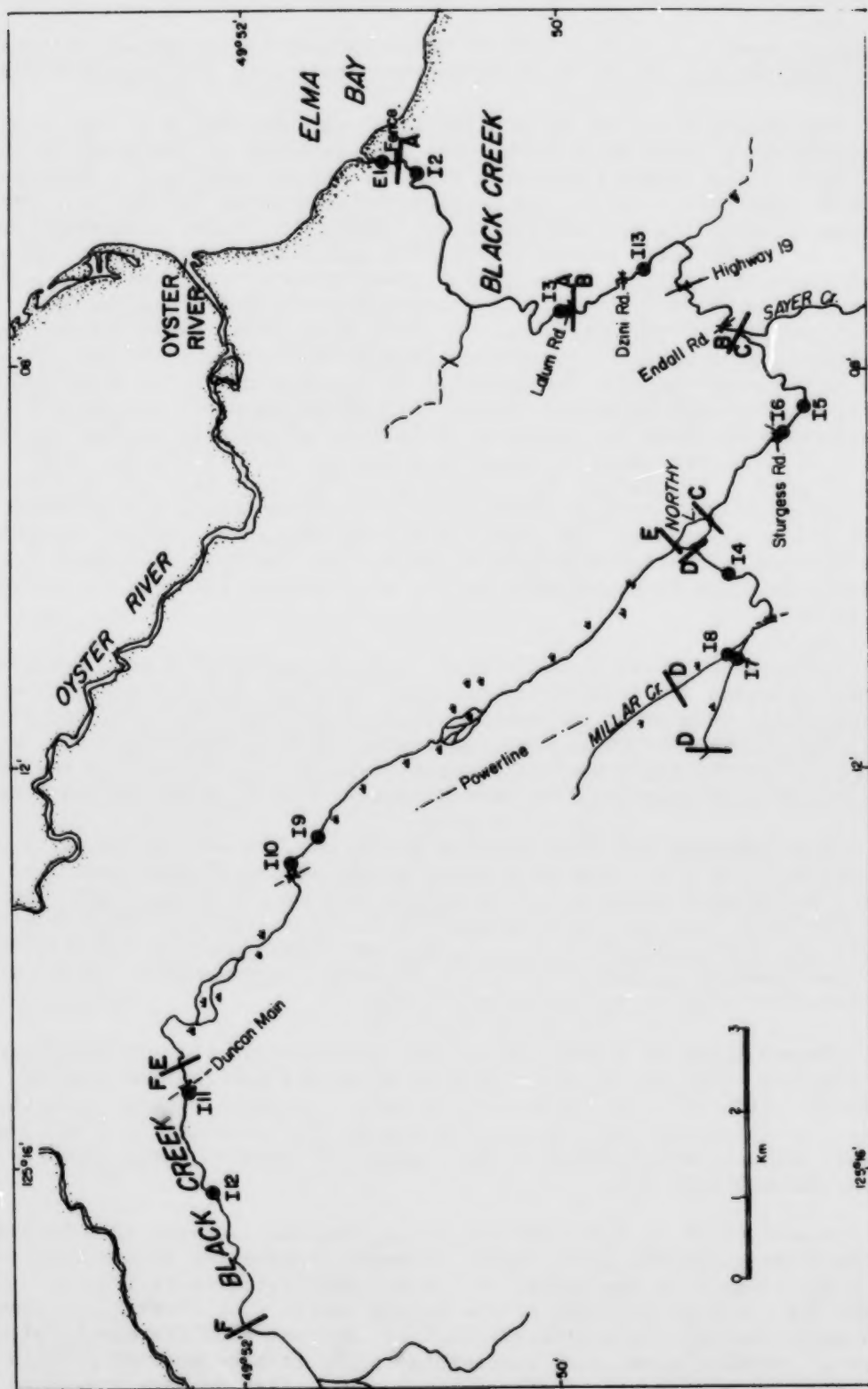


Fig. 2. Map of Black Creek showing location of strata (A-F), index sites (I1 and I2-I13), fence, and major access points.

northeasterly direction until it enters Comox harbour in the Strait of Georgia. The intertidal section of the river is approximately 1 km long and 30 m wide.

The mainstem of the Trent River is 30 km long, but only the first 10 km are accessible to anadromous fish. The average width of the river in the lower 10 km is 16 m. Seven kilometres from the sea, Bloedel Creek connects to the mainstem, but this creek is inaccessible to adult coho because of a series of falls and cascades in the lower sections (Fig. 3). Eight kilometres from the sea, a 15 m high falls prevents fish from reaching the upper sections of the Trent River, including its two tributaries; Tremain Creek and Idle Creek. Steep and high banks with very little overgrowth are found along the main section of the river. Throughout most of this area, cover is mainly in the form of logging debris, which is particularly abundant in the 1-2 km section upstream of the river mouth. The riverbed is composed mostly of solid bedrock with rocky outcrops and boulders. Along the middle and upper reaches of the river, substrate suitable for spawning is scarce, and usually consists of shale material. In the lower reaches, spawning substrate is more abundant and consists of gravel, cobble and shale deposits. The river has many pools as well as shallow areas. Seasonal fluctuations in water levels are pronounced, and large floods are common, particularly during the winter. Flows exceeding 150 m³/s have been recorded during fall and winter. During the summer, flows occasionally decrease to negligible levels, with several sections in the lower reaches becoming dry.

Escapement estimates by fishery officers show annual coho escapements have rarely exceeded 350 fish during the past 10 years (Hancock and Marshall 1985), presumably because of the lack of cover, spawning substrate, and rearing habitat. During the 1985-86 seasons, upstream migration began in early October and peaked around the third week of October (Labelle in prep). Thus the run seems to extend over a longer time period than in French Creek and Black Creek.

Coho spawning has been reported throughout the accessible parts of the system, with the best spawning grounds being located in the lower 2 km of the river, in isolated areas along the middle reaches and China Creek. In 1985 and 1986 fish were reported to be attempting to return to their release sites in Bradley Lake and congregated near the Bloedel Creek junction (Labelle in prep). Coho spawning occurred throughout November and December of 1986, with peak in activity detected during early December.

French Creek is a small stream on the southeast side of Vancouver Island, starting from the eastern slopes of Mount Arrowsmith, and flowing northeasterly until it connects with the Strait of Georgia west of Parksville (Fig. 1). The intertidal section of this system is approximately 1 km long, 100 m wide, and is characterized by the presence of several small channels meandering through mud flats.

French Creek is approximately 20 km long and averages 12 m in width at its middle sections (Fig. 4). Numerous small falls exist in the mainstem between 7 and 13 km from the mouth. A fishway was installed in 1961 to facilitate fish passage over one of the larger falls. The creek bifurcates into two major sections approximately 12.5 km upstream from the mouth, with only part of the West Fork being accessible to the fish because of a falls located about 400 m above the confluence. However, fish do have access to the East fork which splits into several sections in the upper reaches, 16.8 km from

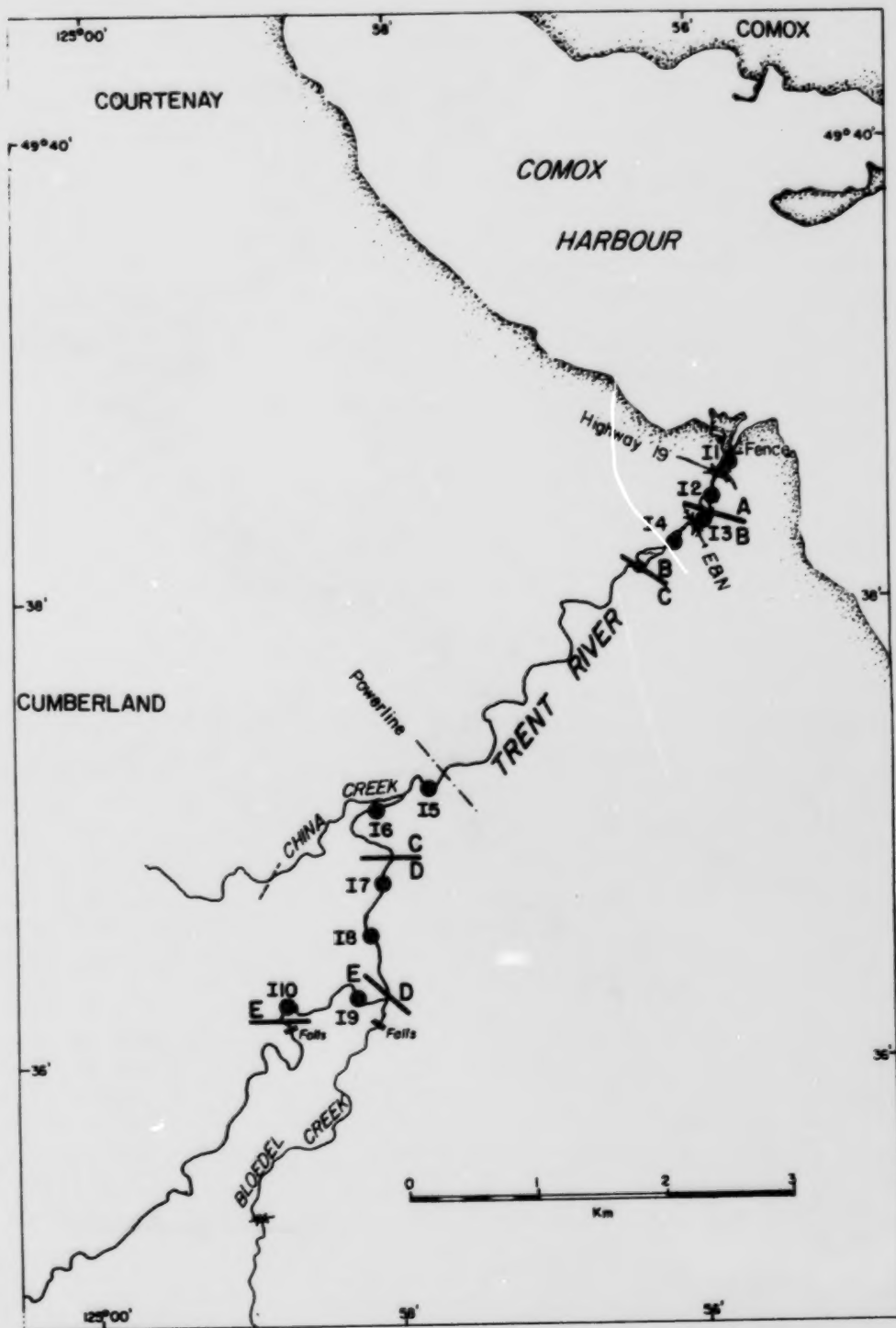


Fig. 3. Map of Trent River showing location of strata (A-E), index sites (I1-I10), fence, and major access points.

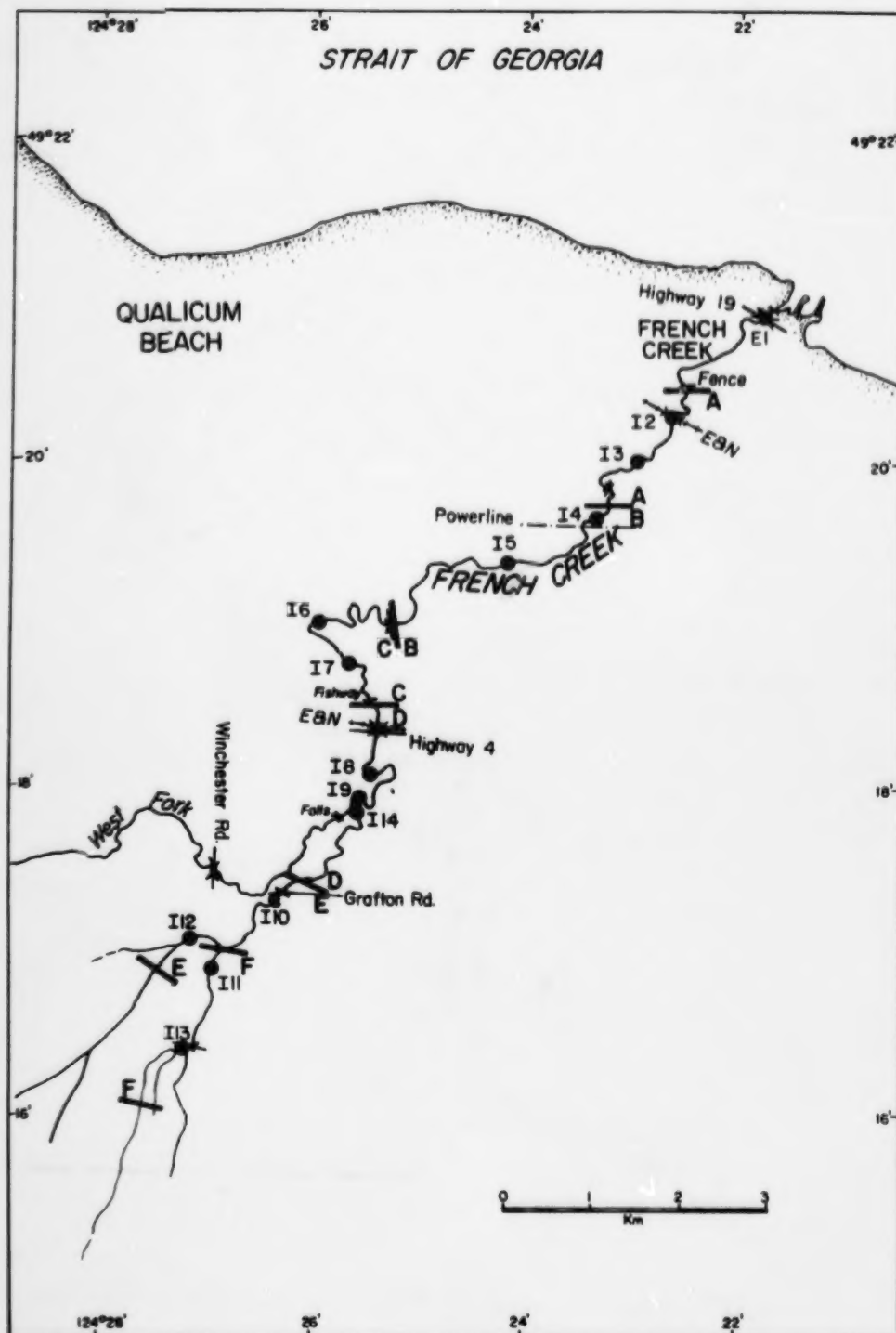


Fig. 4. Map of French Creek showing location of strata (A-F), index sites (E1 and I2-I14), fence, and major access points.

the mouth. The creek is characterized as having many pools, and large seasonal fluctuations in water levels. Discharge during winter floods can exceed 15 m³/sec. and usually decreases to negligible levels during summer.

Mainly because of the abundant vegetation cover, Hancock and Marshall (1985) described the system as a good coho producer, with annual escapement reaching 3500 fish in the previous 10 years. Coho spawn throughout the system, with good spawning grounds located at the confluence of the East and West forks, and adjacent to Winchester Road in the upper reaches of the system. Spawning also occurs in isolated areas throughout the lower 6.5 km of the system.

As in Black Creek, upstream migration is governed by the arrival of fall rains. Labelle (in prep) noted that during 1985 and 1986, upstream upmigration began around mid-October and mid-November respectively. In both cases, over 80% of the adults escaping to the system moved upstream during the first week of upmigration.

FENCE COUNTS AND MARK-RECAPTURE ESTIMATES

Collapsible, adult fish counting fences have been operated on Black Creek, French Creek and the Trent River since 1985 by researchers from the Department of Fisheries and Oceans (DFO) and the University of British Columbia (UBC). The locations of the adult fish counting fences on each stream are shown in Figs. 2-4.

In 1987, the fences became operational well before any fish had moved upstream and, throughout the season, they were usually operated during all daylight hours, 7 days a week. Fish captured overnight and during the course of the day were dipnetted out of the traps, processed and released upstream. Prior to release, all coho captured were marked by means of an opercular hole punch. Processing also involved sexing the fish, recording each as jack or adult, and examining the fish for fin clips.

It was realized that a complete enumeration of all adult coho at the fences would probably not be possible due to flooding, and an unknown portion of the population would escape undetected. Therefore, mark-recapture operations were conducted by UBC researchers as a secondary estimate of escapement in each of the three systems.

As mentioned previously, all coho caught at the fence were marked with an opercular punch prior to release. Subsequent recoveries were made throughout the season by a field crew using an electrofisher. In each stream several sampling sites were selected based on accessibility, the presence of spawning substrate and geographical locations. Each fish caught was examined for marks and released. Recoveries were made on 2 occasions in Black Creek, 5 occasions in Trent River, and 3 occasions in French Creek.

The mark-recapture estimate was derived using a sequential Bayesian method (Gazey and Staley 1986). The Bayesian approach determines the likelihood associated with estimates of abundance based on the joint

probability distribution of recovery rates. Maximum likelihood estimates of abundance and associated confidence intervals were obtained from the frequency distribution of probabilities.

BLACK CREEK AND FRENCH CREEK SAMPLING DESIGN

The visual survey sampling designs tested were: simple random sampling (SRS), stratified random sampling (SSRS), index sampling (IS) and stratified index sampling (SIS).

To define the sampling universes for random sampling and to select the specific sample sites for index sampling, each stream was surveyed during early autumn when flows were low. At this time, all areas of each stream accessible to us were identified. For the purposes of stratified sampling, French Creek and Black Creek were stratified geographically based on habitat type (Figs. 2 and 4). There were a total of six strata in each of French Creek and Black Creek. In the case of Black Creek, one additional stratum consisted of Northy Lake (Fig. 2). Since we were unable to sample the lake, population estimates from Black Creek were derived for the complete system excluding the lake, and hence, are known to be an underestimate of the total population, at least on a statistical basis.

The sampling universe for random sampling in French Creek and Black Creek, consisted of all 250 m units in each stratum. Our selection of 250 m as the length for survey units in French Creek and Black Creek was based on an a priori simulation analysis (Appendix A). Two random sites were chosen from the set of 250 m units in each stratum (on French Creek and Black Creek). Different sites were randomly selected during each survey period throughout the spawning period. A total of 12 random sites for each of French Creek and Black Creek were sampled during every survey.

Two index sites were usually selected per stratum at French Creek and Black Creek. This was considered sufficient to ensure adequate representation of the different habitat types in each of the strata while remaining reasonably accessible (Figs. 2 and 4). In selecting index sites, consideration was given to substrate quality, habitat unit type, overhead cover, and instream cover. The basic biophysical attributes of the index sites are provided in Appendix B. There were a total of 12 index sites for each of French and Black creeks. One additional index site was added to stratum D in French Creek during the first sampling period to ensure that the diversity of habitats in that stratum were adequately represented. Some of the index sites in French Creek were the same sites used in the study conducted in 1986 (Johnston et al. 1987). This allowed us to examine the year to year variability of certain instream indexing methods.

Since our approach was based on a stratified sampling design for both random and index designs, and sites were always chosen from the subset of 250 m units in each stratum, our unstratified random sampling design was not completely random throughout the entire system. To follow a complete random design would have required the repeated selection of 250 m sites from the complete set of all 250 m units in the whole river. We did not have the

resources to do this. However, we wanted to ensure that replicate samples were dispersed over the entire river. Hence, our simple random sampling design was an interspersed random sampling design. Such interspersed replicates in accordance with the distribution of the population in question is one of the most critical aspects of the design of a mensurative experiment (Hurlbert 1984). We were still able, however, to assess the gain in precision due to stratification for both random and index designs using formulae provided by Cochran (1977; p. 95-136).

We compared escapement estimates of coho derived from our simple random sampling design using sample unit lengths of 50, 100, 150, 200, and 250 m for French Creek and Black Creek. We also compared sample sizes (i.e. number of sites) of 4 to 12 for each system. We selected the above ranges in level of sampling effort based on our a priori simulation analyses (Appendix A), and study design. Simple random sampling was the design chosen for the comparisons of sample size and survey unit size because it allowed us to vary the number of samples from 4 to 12, whereas stratified sampling would not.

Foot Surveys

All index and random survey units were sampled 3 times on French Creek, and 5 times on Black Creek. Surveys commenced within 3 to 7 days following the first significant passage of coho above the counting fences. With the exception of a 14 day period when inclement weather and flood conditions on all rivers prevented assessments, we conducted surveys at 5 to 7 day intervals until 20 December 1987.

The visual foot counts were conducted by a two-man crew walking upstream through the survey area. The observers carried 2 m poles to dislodge coho from under cutbanks, rocks, and logging debris. The observers worked together as a unit. In narrow sections of the stream, one observer would walk behind the other. In wider sections of the stream, they progressed together, one on each side of the stream. Coho densities were low enough that the movements of individual fish could be followed when disturbed so that double counting was unlikely. Surveys were done when flow conditions permitted good visibility. The numbers of live and dead coho were recorded for each 50 m section of each 250 m survey unit in Black and French creeks. Counts were also recorded separately for pools, riffles, and runs.

Surveys were conducted along the river beginning with survey units in the headwaters and progressing downstream to minimize double counting due to the general upstream migration of fish. It generally took 4 days to complete the 24 sites assessed during each survey period. Three random and three index sites were surveyed on each day to minimize the chances of temporal pseudoreplication (Hurlbert 1984).

TRENT RIVER SAMPLING DESIGN

Our objective at the Trent River was to evaluate the different sampling designs used in the other two systems using data on the actual fish

distribution and computer simulations. Data on the actual distribution of coho was obtained using snorkel surveys.

As for Black Creek and French Creek, we evaluated simple random sampling, stratified random sampling, index sampling and stratified index sampling by simulating foot survey observations on the Trent River. Five strata were selected on the basis of the actual distribution of adult coho in the river (from snorkel surveys) and according to habitat characteristics (Fig. 3). Five index and two random sites were then chosen per stratum. We compared sample unit lengths of 100, 200, and 300 m for the Trent River.

Snorkel Surveys

Snorkel surveys were conducted on the Trent River 4 times between 20 November and 20 December 1987. The number of adult and jack coho was recorded by 100 m interval and by habitat type along the entire length of the river accessible to coho. Counts from these surveys were used to compare the accuracy and precision of the various foot survey sampling designs and effort levels using computer simulated foot surveys.

The snorkel counts were conducted by one diver floating the entire length of the river with one person accompanying on foot. Pool areas of the river tended to be narrow and visibility was generally good enough to permit nearly a complete census of coho in these areas. Non-pool areas of the river were generally shallow and wide. These areas were enumerated by both persons walking together while checking cutbanks and debris areas for coho.

EFFICIENCY OF VISUAL FOOT SURVEYS

The efficiency of observing adult coho during foot surveys was measured on four occasions at **Black Creek** by reference to the actual number of adults and jacks in survey units using electrofishing. Immediately after conducting a foot survey in a 50 m section, a separate two-man crew electrofished the section. Although the survey sections were not blocked to prevent fish movement out of or into the area, there were no indications that fish numbers changed during the 30 minutes between counts. Efficiency measures for adult and jack coho were made separately for pools, riffles, and runs. Overall average efficiencies and associated variances were then calculated across all habitat types and survey units.

For **French Creek**, the extremely low numbers of coho observed by foot surveys and captured by electrofishing prevented calculation of the efficiency of observing adult coho on foot. Since efficiencies for adults were determined in 1986 by Johnston et al. (1987), we used their efficiency estimates to expand our foot counts.

Efficiency measures comparing foot surveys with float surveys in pool areas of the **Trent River** were conducted on four occasions. Three or four different observers were asked to provide a visual count of the number of adult and jack coho in each of four different pools in the upper headwaters of the

river. A diver then snorkeled in the pool and estimated the number of adult and jack coho.

The average efficiency for pool areas was then used as an overall efficiency measure for foot surveys for the entire river. We feel that this is a reasonable representation of the overall efficiency since the majority of coho in the Trent River were found in pools or runs with good visibility. The overall efficiency of foot surveys to float counts was then adjusted on the basis of the estimated snorkel survey efficiency of 80%. This allowed us to relate the foot survey counts to the actual number of fish present in the area. Although we have no empirical basis for this figure of 80%, we feel it is reasonable given the clarity of the water and the lack of cover available for fish.

SURVEY LIFE

At French Creek and the Trent River, where we surveyed the entire system, we equated survey life to the estimated number of days adult coho spent alive in the stream (stream life). For Black Creek, where we were unable to survey Northy Lake, we equated survey life to the estimated number of days coho spent in each of two survey areas; below Northy Lake and above Northy Lake. We also determined stream life for Black Creek and compared it to the values for the two survey areas.

Survey life was determined at Black Creek and the Trent River from tagging studies. Adult coho were tagged with Petersen disks soon after the fish entered each system and counts of these tagged fish were recorded during subsequent foot surveys. Numbers of tagged fish observed at each site were then used to estimate the number of tagged fish remaining in each stratum for each survey. The estimated number of tagged fish was then plotted against time and a curve was fitted. Survey life was calculated for each area by dividing the respective area under the 'tag depletion' curve by the total number of tags initially applied.

At **Black Creek**, Petersen disks were applied to 68 adult coho at the counting fence 7 days after the first passage of fish. As mentioned above, two separate measures of survey life for Black Creek coho were determined for strata below Northy Lake (including Millar Creek) and strata above the lake. An estimate of stream life for the whole creek was obtained by pooling the tag abundance data for the entire creek.

In the **Trent River**, Petersen disks were applied to 43 adult coho in pools in the upper reaches of the river, 9 days after the first passage of fish past the fence. In addition, different coloured tags were applied to 12 adult coho captured by electrofishing in the lower 2-2.5 km of the river. Subsequent tag observations were made throughout the spawning period during the snorkel surveys. Observations were expanded for observer efficiency, tag depletion curves were generated, and average survey life was estimated.

Relatively low fish numbers prevented us from conducting an adequate tagging program on **French Creek**. Hence, stream life was estimated using

combined information from fence counts and foot surveys. A population mortality model was developed which determined stream life for adult coho using an interactive approach incorporating all available information from fence counts and foot survey counts. The model simulated the migration of coho into each river using data from the fence counts. Different mortality rates were then applied at different stages of the run to approximate the total number of adult coho in each system at a given time as estimated from foot surveys counts. We assumed that no fish were left in the creek by 2 January. The total number of fish-days in the creek was then calculated and divided by the estimated escapement (mark-recapture) to determine the average stream life.

Stream life values were also calculated using this method for Black Creek and the Trent River for comparisons with our results from the tagging operations.

ESTUARY COUNTS

Prior to and during the early stages of upstream migration at Black and French creeks, visual foot survey counts of coho were made at 250 m long sites just at the upstream end of tidal influence on Black Creek (Fig. 2) and French Creek (Fig. 4). Preliminary observations suggested that these locations might serve as holding areas for coho in years when migration is delayed by prolonged drought, as was the case in 1987. Also, since fish numbers in such areas are occasionally used by fishery officers as indices of abundance and estimates of escapement, we wanted to evaluate such areas for their potential use as index sites.

Counts from these sites were expanded to peak live counts and total number of fish-days (not divided by survey life, since this is unknown and likely to be highly variable). The estuary counts were also not corrected for the efficiency of foot surveys which would be different from the rest of each river.

ESCAPEMENT ESTIMATION

The methods for deriving the sample estimates (mean density of coho) and variances for stratified sampling designs are provided in Cochran (1977).

For the unstratified designs, the mean density of coho per survey unit for each sampling period (i) was calculated as:

$$(1) \quad \text{DENS}_i = 1/n \left[\sum_{j=1}^n \text{COUNT} \right]$$

where COUNT is the observed number of fish in the j^{th} survey unit and n is the number of units surveyed.

For the stratified designs, the mean number of coho per survey unit for each sampling period (i) was calculated as:

$$(2) \quad \text{DENS}_i = 1/N \left[\sum_{h=1}^L N_h \bar{y}_h \right]$$

where $\bar{y}_h$ is the mean number of fish observed in the h^{th} stratum, N_h is the total number of survey units in the h^{th} stratum, and N is the total number of survey units in the river.

The variance formula for this estimate is in Cochran (1977, p. 95). Cochran also describes how to calculate the expected variance of a simple random sample when a stratified random sample has been taken, as was the case in our study (Cochran 1977, p. 136).

Population totals for each sampling period (i) were derived as follows:

$$(3) \quad \text{POP}_i = \text{DENS}_i * N / \text{EFF}$$

where DENS_i is the mean density of fish per sample unit in the i^{th} sample period, N is the total number of sample units in the stream, and EFF is the mean observer efficiency for the entire stream.

Peak live counts were the maximum population estimate for all sample periods (i). AUC escapement estimates were derived as described in detail by Beidler and Nickelson (1980) and Ames (1984). We used the following equation to calculate the area under our escapement curves:

$$(4) \quad A = 1/2 \left[\sum_{i=2}^n (t_i - t_{i-1}) (P_i + P_{i-1}) \right]$$

where t_i is the time of sampling measured from the first day of the upstream migration, P_i is the estimate of the number of live fish in the stream on the i^{th} day and n is the number of observations. Note that $t_1 = 1$ and $P_1 = 0$ for the day when the first fish entered each stream ($i=1$) and t_n is the number of days that live coho are present in each stream, thus $P_n = 0$. For those cases when fish were still observed on the last sampling date (e.g., Trent River), the escapement curve was drawn to zero five days later.

The estimate of the total live fish days (A) was then divided by our

estimated survey life (SLIFE) to yield a coho escapement estimate for each stream.

The variance estimate for the above area estimate (A) must take into consideration the fact that some of the terms in equation (4) are autocorrelated (i.e., change one estimate of P_i and it changes the calculated area in two terms). Since the values for t_i are known exactly, we can collect the P_i shared by two terms (except for the first and last terms) and rewrite equation (4) as follows:

$$(5) \quad A = 1/2 [P_1 (t_2 - t_1) + P_n (t_n - t_{n-1}) + \sum_{i=2}^{n-1} P_i (t_{i+1} - t_{i-1})]$$

where all the variables are as described above and there is no longer an autocorrelation problem because each term contains a different and independent P_i . Therefore, the variance for the above estimate of the area under the escapement curve was calculated using the following equation:

$$(6) \quad V(A) = 1/4 [V(P_1) (t_2 - t_1)^2 + V(P_n) (t_n - t_{n-1})^2 + \sum_{i=2}^{n-1} V(P_i) (t_{i+1} - t_{i-1})^2]$$

where $V(P_i)$ is the variance associated with the estimate of the number of live fish in the stream on day i and t_i is as previously defined. Note, that $V(P_1)$ and $V(P_n)$ always equal zero for the escapement curves, therefore:

$$(7) \quad V(A) = 1/4 \left[\sum_{i=2}^{n-1} V(P_i) (t_{i+1} - t_{i-1})^2 \right]$$

Our estimates of the variance associated with the total coho escapement estimate were derived using the following equation:

$$(8) \quad V(ESC) = V(A)/SLIFE^2$$

which assumes the value for SLIFE is known exactly. Therefore, the confidence intervals for our escapement estimates only reflect the precision associated with the different sampling designs.

RESULTS

ESCAPEMENT TIMING AND INSTREAM DISTRIBUTION

Visual counts of live adult and coho salmon for each system are provided in Appendix C.

AUC population estimates derived from stratified random sampling suggested that peak abundances of adult and jack coho in **Black Creek** occurred on 5 December, approximately 3 weeks after the first passage of fish through the counting fence (Fig. 5). This, however, might be misleading because coho probably reside in Northy Lake for some time before moving further upstream. Population estimates using stratified index counts showed the peak abundance of adults to be on 30 November. Spawning in Black Creek was completed by 18 December. Coho in Black Creek appeared to aggregate into very specific areas of the system. High densities of coho were observed around Sturgess Road, in lower Millar Creek and its south fork, and above Duncan Main Road on the mainstem (see Fig. 2).

The distribution of adult coho between strata in Black Creek changed considerably over time (Fig. 6). There was a clear upstream movement of fish as the season progressed. By 5 December, adult coho were no longer present in the creek below Northy Lake (Strata A, B, and C).

Peak abundances of adult and jack coho in the **Trent River** occurred on 18 November, 10 days after first migrants passed the counting fence (Fig. 7). Abundances declined rapidly after this date and few coho were observed on 20 December. Coho were never observed in the act of spawning except in China Creek, and fish counted in large pools or runs in the upper reaches (6-8 km from the fence), accounted for most of the fish observed during each survey.

Coho in the Trent River showed a highly aggregated distribution both on a large scale over the entire river and on a smaller scale within strata. The distribution between strata of adult coho in the Trent River is shown in Fig. 8. Fish were present in all strata at most times during the season but there were obvious spots of high abundance at certain times (e.g., Strata C and D on 18 November). Observed abundances of adult coho on 20 December were very low (6 fish in entire river).

Peak abundances of adult and jack coho in **French Creek** occurred around 1 December, 7 days after the first passage of coho past the fence (Fig. 9). Abundances of adults declined slowly from this date onwards and no live coho were observed between 20 and 23 December.

Adult coho were observed throughout French Creek with the exception of the upper reaches beyond Grafton Road bridge. However, zero counts of fish in this area were not indicative of a total absence of fish. A few jack coho were observed above Winchester Road and some adult coho were recovered outside of our survey sites using electrofishing. The largest number of adult coho (4)

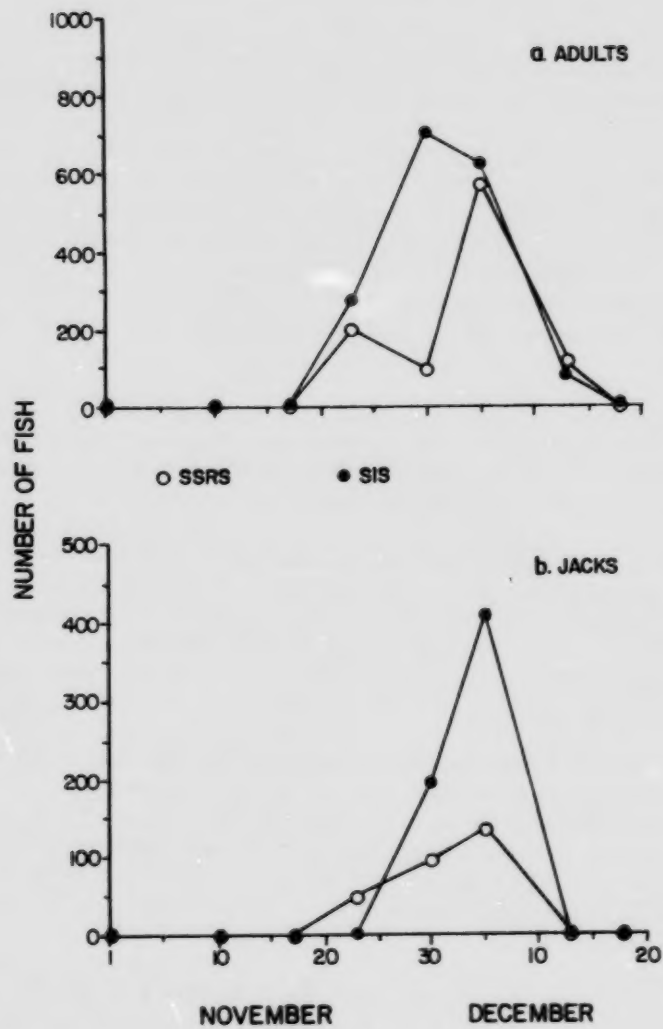


Fig. 5. Escapement curves derived using stratified random sampling (SSRS) and stratified index sampling (SIS) for Black Creek adults and jacks.

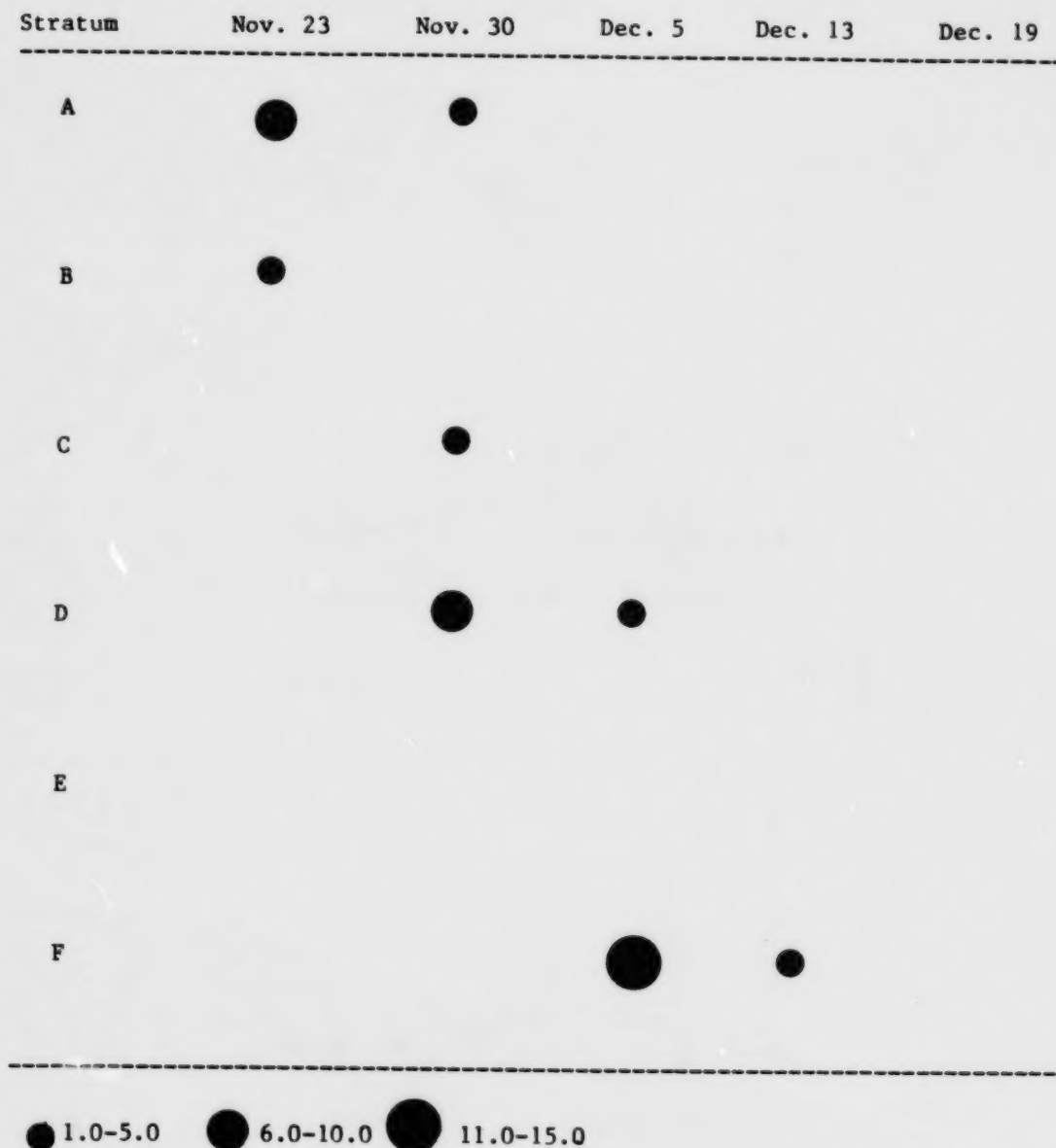


Fig. 6. Instream distribution of Black Creek adults showing changes over space and time. Circles represent the mean number of adult coho per 250 m unit, averaged over all index and random sites in the stratum (n=4). Blanks indicate zero fish seen. Refer to Fig. 2 for location of strata.

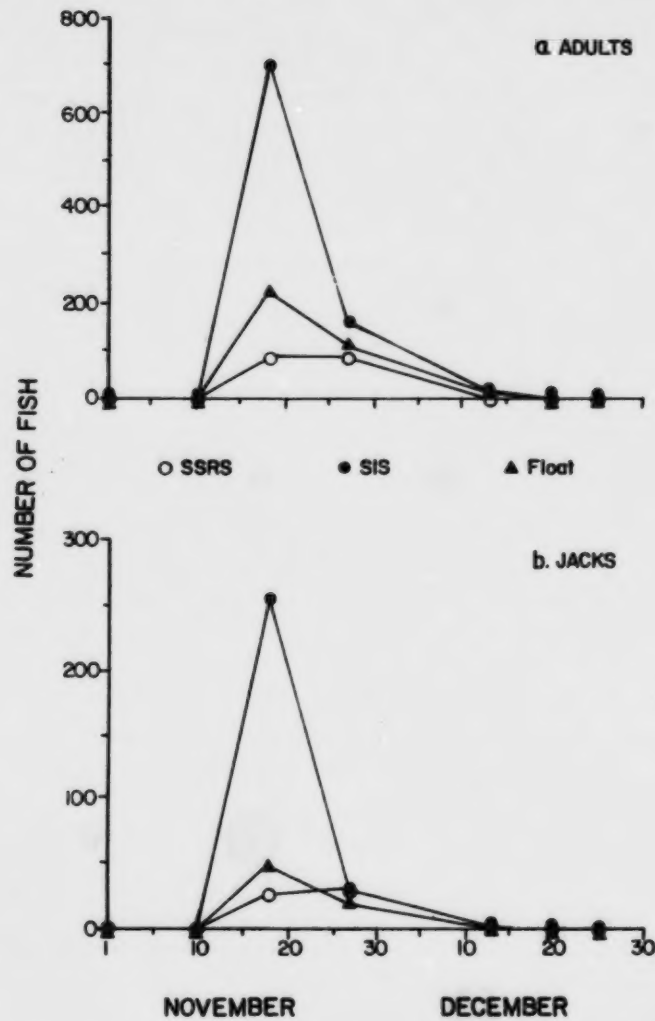


Fig. 7. Escapement curves derived using stratified random sampling (SSRS), stratified index sampling (SIS), and float counts for Trent River adults and jacks.

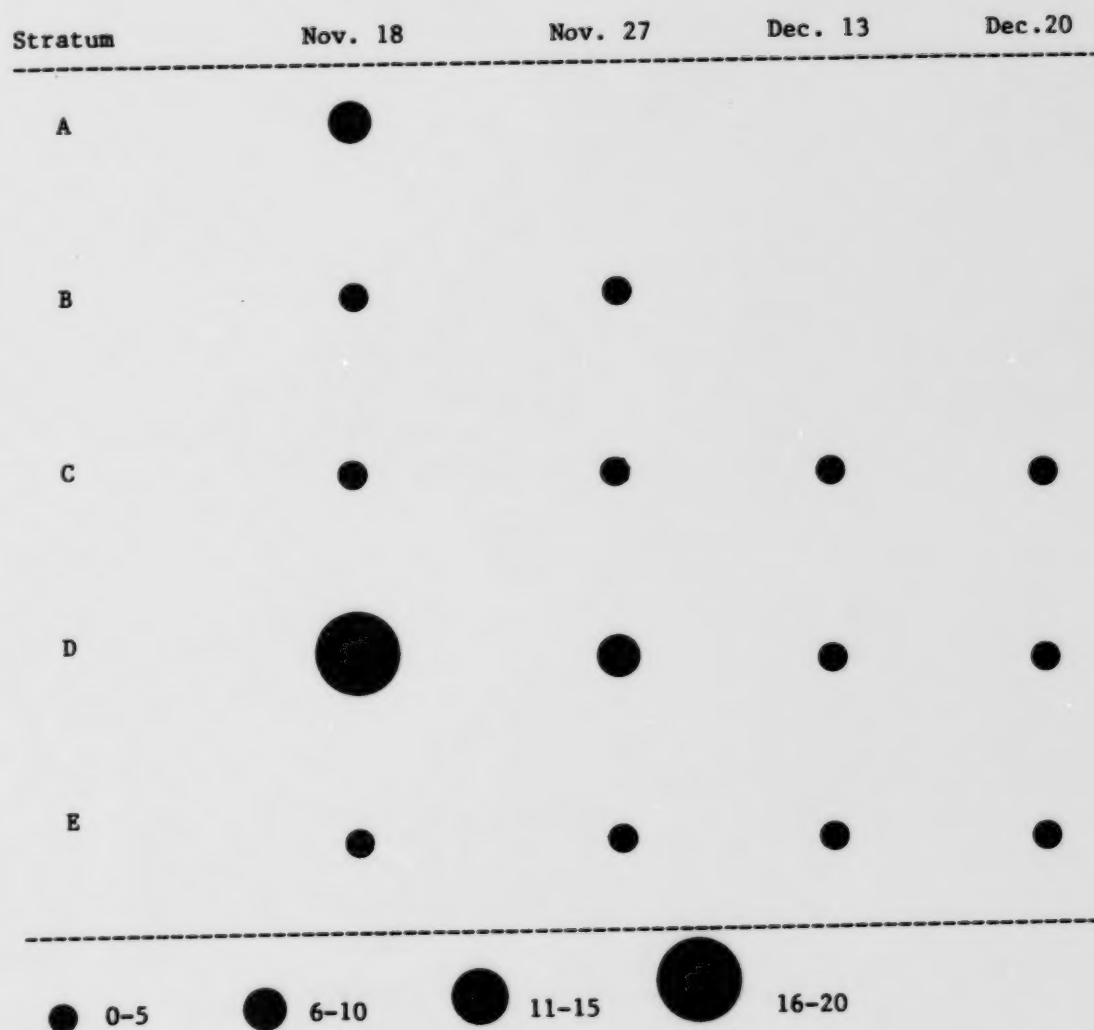


Fig. 8. Instream distribution of Trent River adults showing changes over space and time. Circles represent the mean number of adult coho per 250 m unit, averaged from float survey data. Blanks indicate zero fish seen. Refer to Fig. 3 for location of strata.

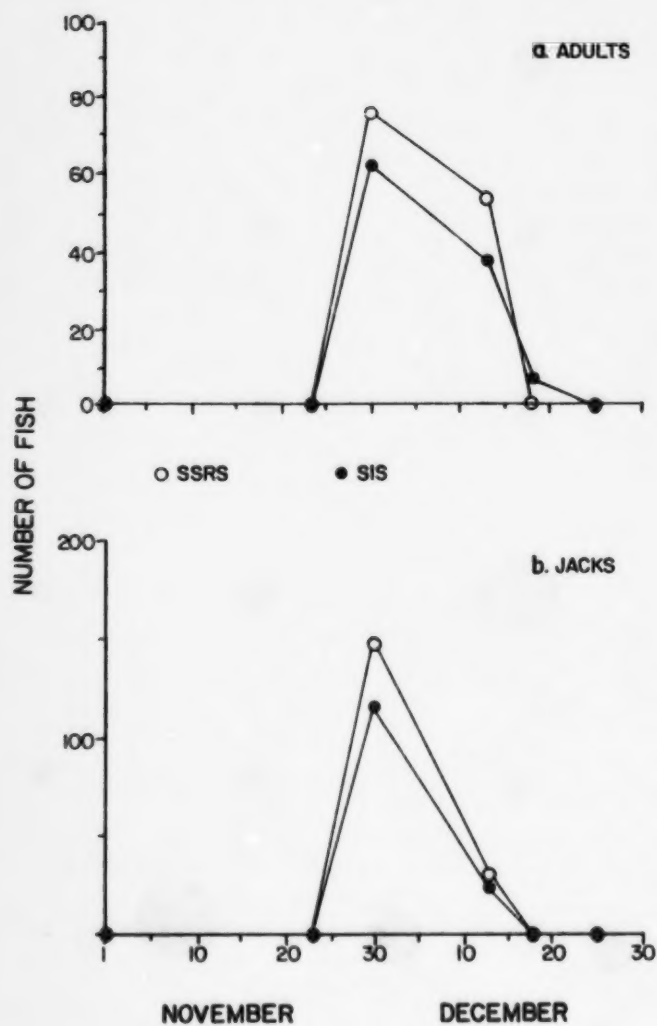


Fig. 9. Escapement curves derived using stratified random sampling (SSRS) and stratified index sampling, (SIS) for French Creek adults and jacks.

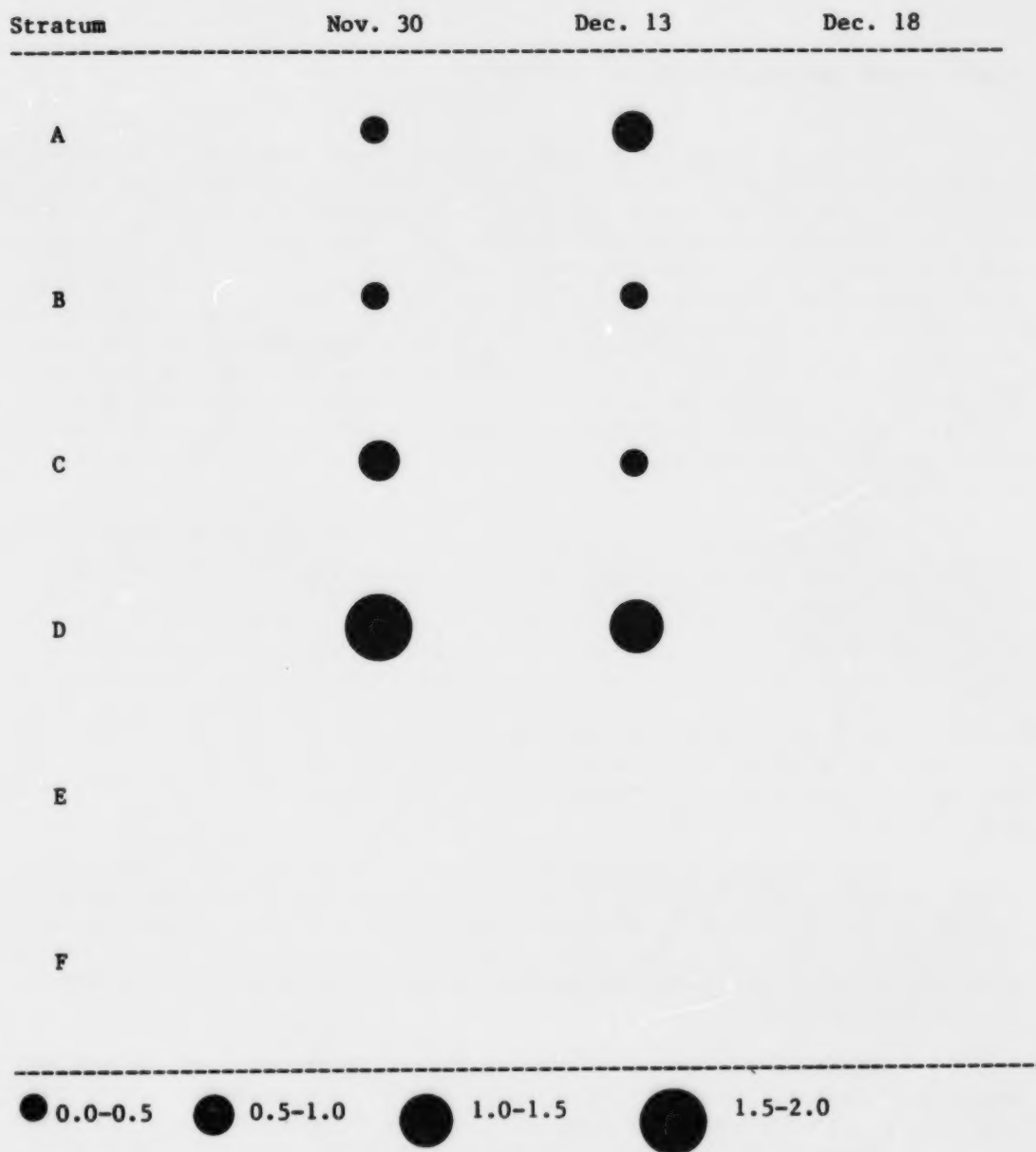


Fig. 10. Instream distribution of French Creek adults showing changes over space and time. Circles represent the mean number of adult coho per 250 m unit, averaged over all index and random sites in the stratum ($n=4$). Blanks indicate zero fish seen. Refer to Fig. 4 for location of strata.

was observed in a single site (I14) in stratum D. The relative distribution of adult coho between strata in French Creek did not change over time (Fig. 10).

FENCE COUNTS AND MARK-RECAPTURE ESTIMATES

Upstream migration of coho in **Black Creek** began on 11 November with the first fall freshet. However, it wasn't until 17 November that significant numbers of fish migrated past the fence (260 adults). A total of 714 adult coho and 525 jack coho were enumerated at the fence and allowed to continue upstream (Table 1). Favourable water conditions in Black Creek allowed enumeration of an estimated 91% of the adults and almost 50% of the jacks returning to the creek. Although mark-recapture censuses were made throughout the season, fish were only found during a short period of time. As a result, data from only 3 recovery surveys could be used to estimate the size of the population. A total of 41 adults and 21 jacks were examined during these 3 surveys. The maximum likelihood (ML) estimate of the number of adults in Black Creek was 785 individuals, while the ML estimate of the jack population was 1071 fish (Table 1).

Substantial upstream migration of coho in the **Trent River** started on 10 November with the first period of high water. On this date, at least 100 coho moved upstream. Large floods occurred frequently between 1 December and 12 December, preventing the counting of fish during much of this period. During the season, 144 adult coho were caught at the fence and released upstream (Table 1). A total of 10 jacks were caught and released upstream.

Mark-recapture censuses were made on 14, 19, 28, 30 November and 13 December. A total of 120 unmarked adults and 18 unmarked jacks were collected during these surveys. The maximum likelihood estimates for coho in the Trent River were 909 adults and 86 jacks (Table 1).

The problems associated with fence operation in the frequently flooding Trent River resulted in only a small portion of the estimated coho return being enumerated at the fence, estimated to be 16% of the adults and 14% of the jacks (Table 1). The lower numbers of fish observed at the fence, and during mark-recapture surveys resulted in poor precision of the maximum likelihood estimate.

Upstream migration of coho in **French Creek** began on 23 November with the first freshet. Complete enumeration of the coho escapement was not possible due to frequent flooding. During the season a total of 41 adult coho and 85 jacks were caught at the fence, and released upstream (Table 1).

Although mark-recapture censuses were made throughout the season, fish were only caught in a few instances. As a result, data from only 3 surveys could be used to estimate escapement. A total of 15 adults and 6 jacks were recovered. The ML estimate of the number of adults in the river was 114 fish and the ML estimate of the jack population in the river was 255 fish (Table 1).

Table 1. 1987 coho salmon escapement estimates for Black Creek, Trent River, and French Creek using fence counts and mark-recapture. Fence counts are the known number of fish released into each river above the fence. The percentage of fish observed at the fence and the relative precision of mark-recapture estimates are also shown. Arithmetic means for the frequency distribution used to estimate the coefficients of variation are also provided.

	Mark-Recapture					
	Fence Count	ML ¹	Bounds ²	Percent Obs. at Fence	Arithmetic Mean	CV ³ (%)
<u>Adults</u>						
Black Creek	714	785	739- 923	91.0	814	5.4
Trent River	144	909	631-1668	16.0	1033	25.5
French Creek	41	114	78- 297	40.0	151	37.0
<u>Jacks</u>						
Black Creek	525	1071	798-1861	49.0	1222	22.8
Trent River	10	86	40- 194	14.0	114	38.8
French Creek	85	255	143- 582	33.0	381	39.9

¹ maximum likelihood estimate

² 95% probability range

³ standard deviation divided by arithmetic mean for frequency distribution

Adult and jack coho marked at the French Creek fence constituted only 40% and 33%, respectively, of the maximum likelihood estimates. The low number of fish counted at the fence and recovered during the mark-recapture surveys resulted in poor precision (Table 1).

The results from the fence counts and mark-recapture estimates for all systems indicate that there is a great deal of uncertainty associated with each mark-recapture estimate except for Black Creek adults (Table 1). A second observation is that the precision of the mark-recapture estimates tends to be poorer for jacks than for adults, except for French Creek where the adult population was very small. Finally, it should be noted that for each population estimate the arithmetic mean was greater than the maximum likelihood estimate, thus indicating that all the distributions used to produce the coho population estimates were skewed to the right.

ACCURACY OF ESTIMATES

AUC escapement estimates and peak live counts obtained from simple random sampling (SRS), stratified random sampling (SSRS), index sampling (IS), and stratified index sampling (SIS) were compared with the mark-recapture estimates. The AUC estimates were derived by dividing the area under the escapement curve by the appropriate average survey life for each system. Survey life was calculated as 8.0, 11.0, and 13.3 days for Black Creek, the Trent River, and French Creek respectively. The methods for determination of these survey life values and their effect on escapement estimates is discussed in a later section.

Index counts of adult coho in Black Creek and the Trent River yielded higher AUC escapement estimates than did random counts (Fig. 11a and b). However, the accuracy of all methods relative to the mark-recapture estimates differed for each system (Fig. 11, Table 2). For Black Creek adults, random sampling was the most accurate, while for Trent River adults, index sampling was more accurate. No significant difference was apparent between survey designs for French Creek adults and jacks (Fig. 11c and 12c). Perhaps this reflects how well the index sites were chosen in relation to the distribution of fish in each system. In French Creek, we found that the adult coho were distributed more or less uniformly throughout the system (Fig. 10), so there was little difference in the accuracy of the survey designs. The results for Black Creek suggest most of the index sites were in areas with high abundances of adult coho, while random sites were more representative of the average number of adults in the system. If more index sites had been selected in low abundance areas of Black Creek, the AUC escapement estimates derived using IS and SIS would have been lower. This is likely the case for the Trent River as well (Fig. 11b). At the Trent River, index sites were selected based on the observed distribution of adult coho in the system, and hence were representative of actual conditions. On the other hand, the random sites selected occurred in areas of low abundance and therefore underestimated the abundance of adult coho.

For jack coho, index counts in Black Creek and the Trent River also tended to produce significantly higher AUC escapement estimates than did random

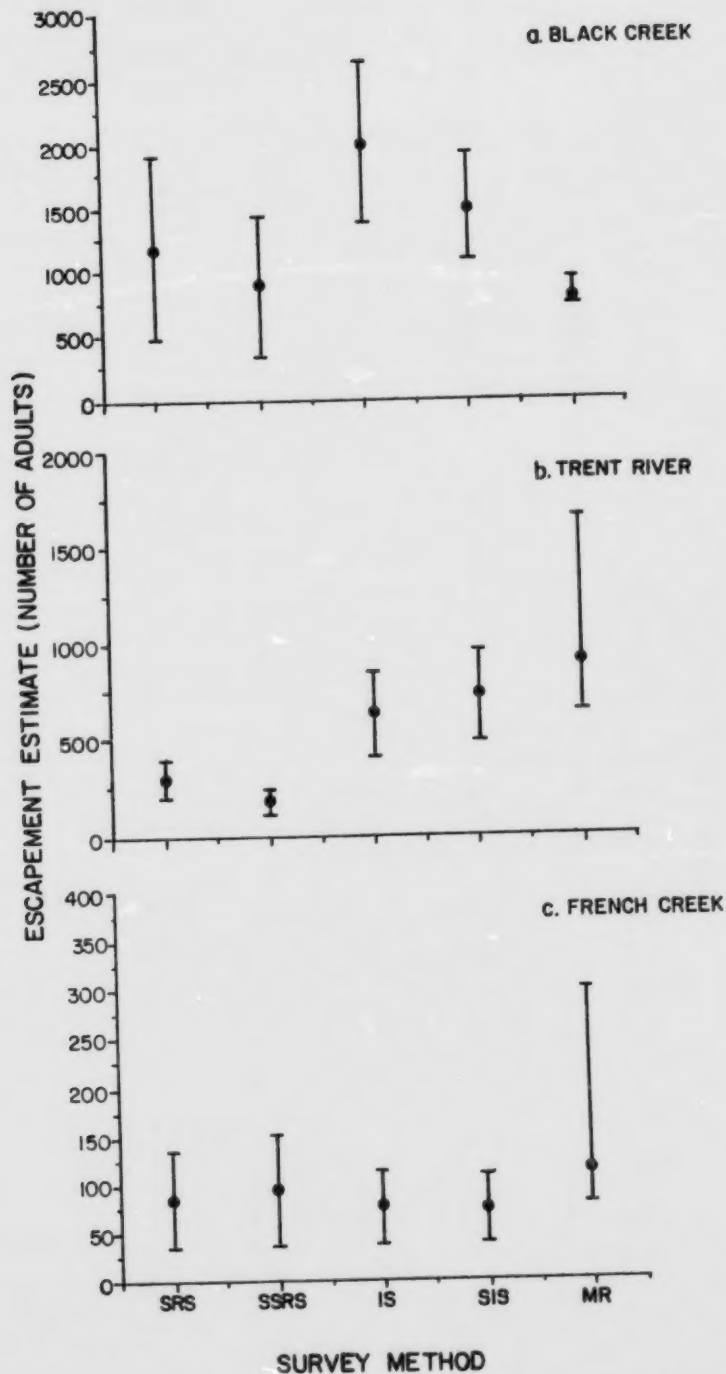


Fig. 11. AUC escapement estimates for adult coho derived using various survey designs and escapement estimation methods at Black Creek, Trent River, and French Creek. SRS is simple random sampling, SSRS is stratified random sampling, IS is index sampling, SIS is stratified index sampling, and MR is the mark-recapture estimate. Error bars for the foot survey designs represent 95% confidence intervals. Error bars for the mark-recapture estimate represents 95% probability ranges.

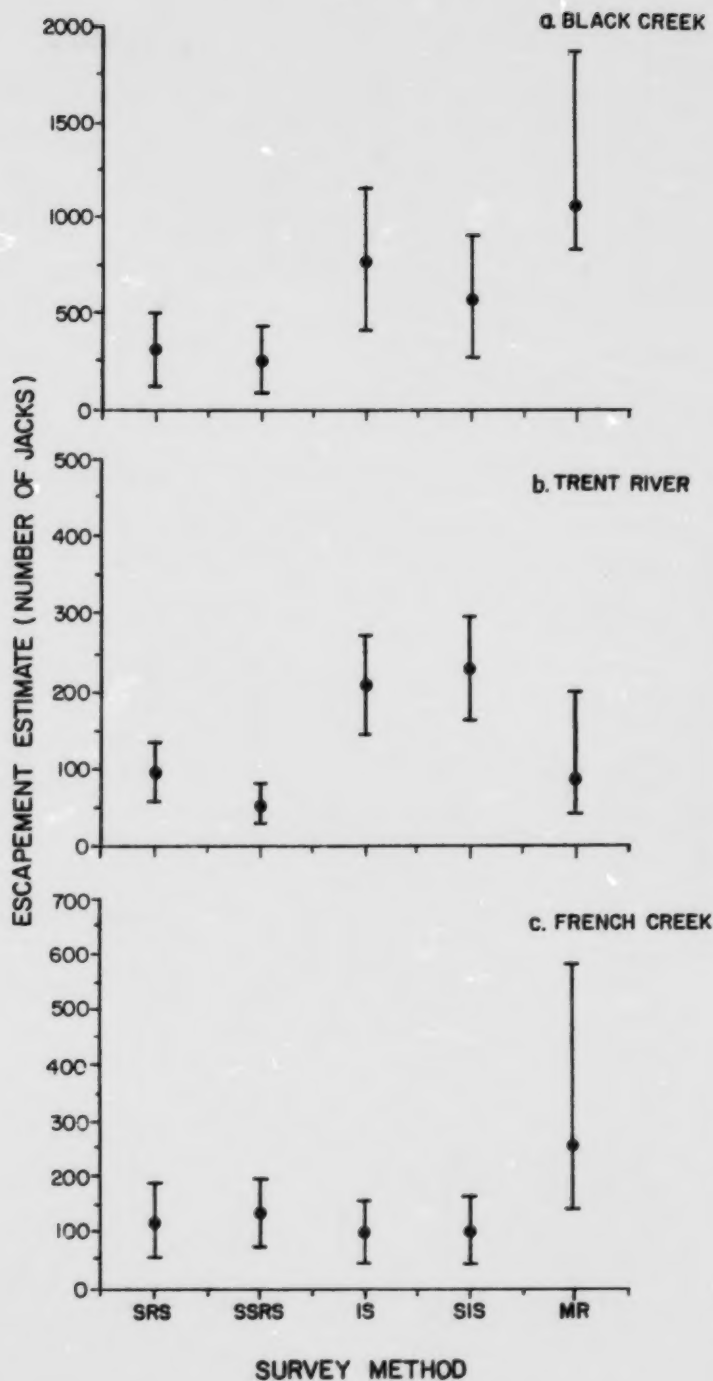


Fig. 12. AUC escapement estimates for jack coho derived using various survey designs and escapement estimation methods at Black Creek, Trent River, and French Creek. SRS is simple random sampling, SSRS is stratified random sampling, IS is index sampling, SIS is stratified index sampling, and MR is the mark-recapture estimate. Error bars for the foot survey designs represent 95% confidence intervals. Error bars for the mark-recapture estimate represents 95% probability ranges.

Table 2. AUC escapement estimates as a percentage of the mark-recapture estimate for adult and jack coho at Black Creek, Trent River and French Creek. Survey unit lengths were 250 m for Black Creek and French Creek, and 200 m for the Trent River. Bold numbers indicate the most accurate design for each system.

	Sampling Design			
	SRS	SSRS	IS	SIS
<u>Adults</u>				
Black Creek	150.0	113.1	255.2	191.0
Trent River	31.7	18.5	69.4	80.0
French Creek	74.7	82.5	66.9	65.1
<u>Jacks</u>				
Black Creek	29.7	23.8	73.1	54.5
Trent River	110.5	62.8	241.9	266.3
French Creek	46.3	52.2	38.8	40.4

counts (Fig. 12a and b). However, the accuracy of these methods relative to the mark recapture estimates was different from adult coho and varied between systems (Fig. 12, Table 2). For Black Creek jacks, index sampling was more accurate than random sampling. For Trent River jacks, random sampling tended to be more accurate. There was no significant difference in the accuracy of the various methods for French Creek jacks.

Area-Under-Curve Estimates

The accuracy of the AUC escapement estimates derived using simple random sampling (SRS) was dependent on the survey unit length and the number of sample sites (Fig. 13 and 14). However, the relationship varied substantially depending on the system and the type of fish (i.e., jack or adult).

For **Black Creek** adult coho, the accuracy of AUC escapement estimates using simple random sampling increased with increasing survey unit length and sample number (Fig. 13a). However, the incremental gain in accuracy from increasing the number of samples or survey unit length decreased to the point where the gain was small between 10 and 12 samples and between 200-250 m long units. This indicates that increased survey effort would not substantially improve the accuracy of the AUC escapement estimate for Black Creek.

In the case of **Trent River** adults, the AUC escapement estimates for the various sample sizes converged as survey unit length increased. The point of convergence was roughly at 0.5 of the mark-recapture estimate (Fig. 13b). If the hypothesis of increasing accuracy with increasing survey unit length holds, then these results suggest one of three possibilities; the mark-recapture estimate is too high, our AUC estimate using SRS is too low, because of an overestimate of survey life, or both factors contributed.

The effect of sample size on the accuracy of our Trent River adult AUC estimate using simple random sampling is quite different than for Black Creek adults. Because of the extremely patchy distribution of adults in the Trent River, the addition or deletion of a few sites is enough to produce large changes in the escapement estimate (Fig. 13b). These results suggest that surveying longer reaches is preferable to surveying more sites at the Trent River.

At **French Creek**, the accuracy of the adult AUC escapement estimate using simple random sampling also increased with increasing survey unit length (Fig. 13c). The trend towards a value for AUC/MR of 0.8 indicates that both methods yielded similar estimates. There was also improvement in the accuracy of the estimate with increasing sample size. These results suggest that for French Creek, at least in low abundance years, surveying longer (>250 m) and more (>12) survey units may improve accuracy.

Similar effects of sample size and survey unit size on the accuracy of AUC estimates were evident for jacks in all systems (Fig. 14). Our AUC escapement estimate for jacks approximated the mark-recapture estimate for the Trent River only (Fig. 14b). For Black Creek and French Creek, our AUC escapement estimate for jacks was considerably lower than the mark-recapture estimates (Fig. 14a and Fig. 14c). This phenomenon could again be a result of a mark-recapture estimate which is too high, and for an AUC estimate which is

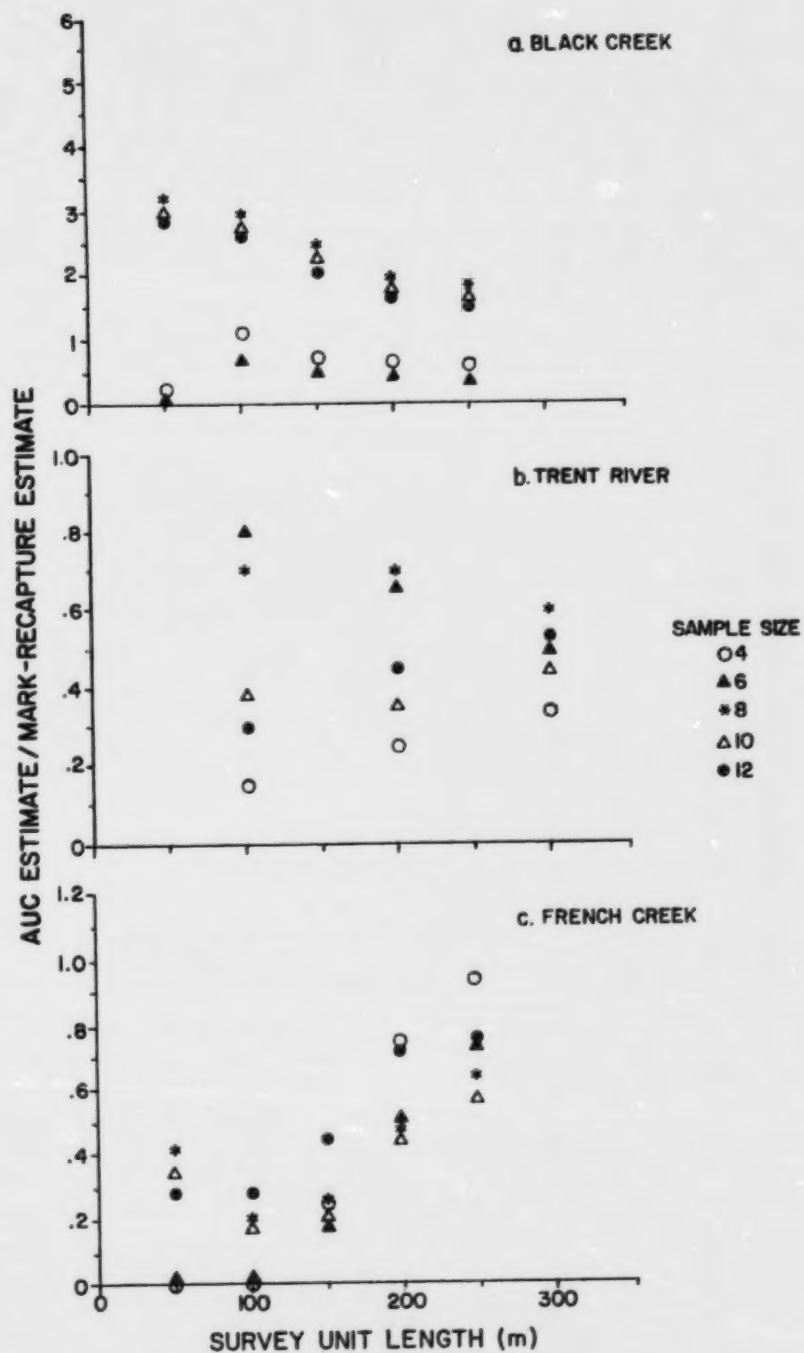


Fig. 13. Effect of sample size and survey unit length on the accuracy of AUC escapement estimates for adult coho derived using simple random sampling.

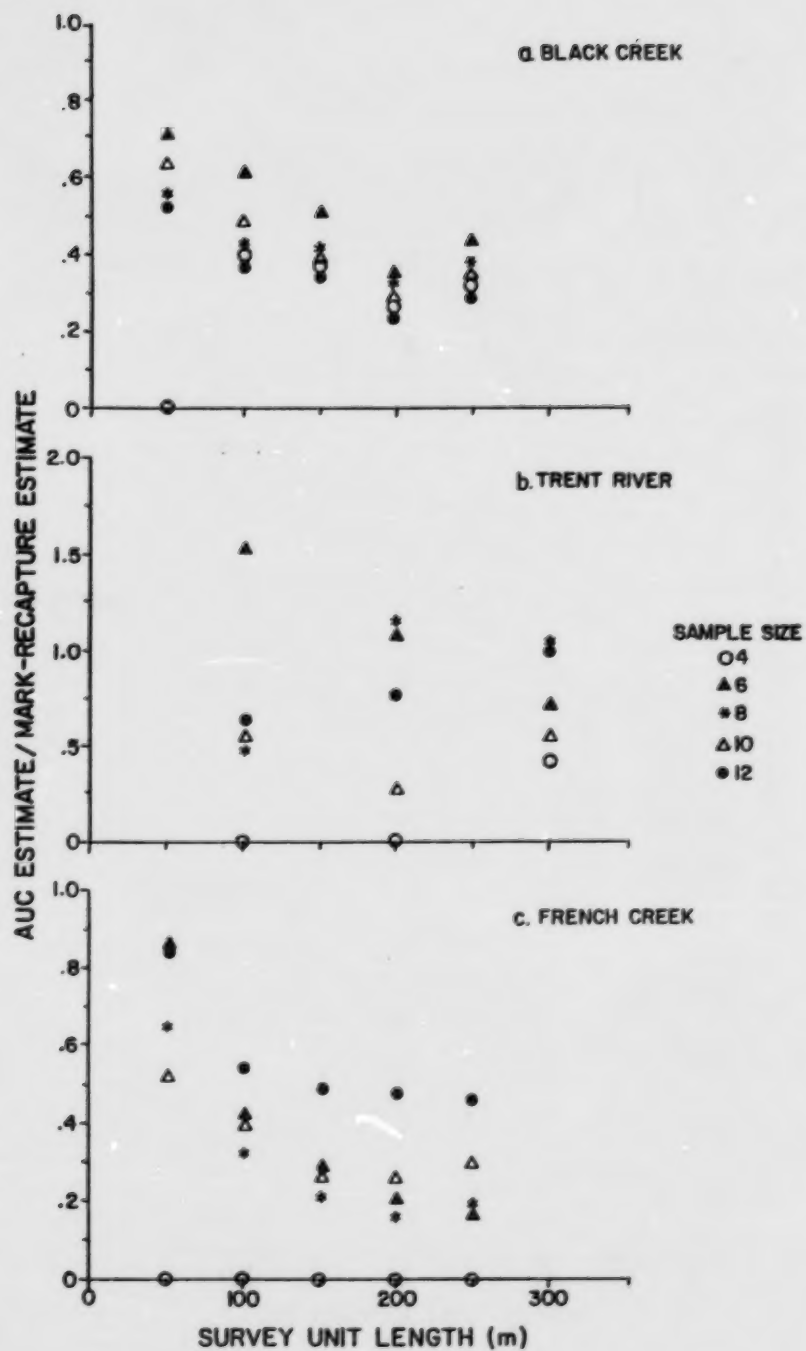


Fig. 14. Effect of sample size and survey unit length on the accuracy of AUC escapement estimates for jack coho derived using simple random sampling.

too low (survey life overestimated). We have assumed in this study that jack coho have the same survey life as adults, an assumption that requires further investigation.

Peak Live Counts

Although peak live counts are only crude indices of escapement, we wished to assess their reliability using different survey designs. Ideally we would measure the degree of correlation between peak live counts and the true escapement over several years. Since this is only the first year of study in the 3 systems, we simply present the peak live counts for each survey method (Table 3) and express them as a percentage of the mark-recapture estimate (Table 4). Although no meaningful comparisons between methods or between systems were made, it is of interest to note that peak live counts of Black Creek adults approximated the mark-recapture estimate reasonably well. For all other systems and survey designs, peak live counts were poor estimates of actual escapement.

PRECISION OF ESTIMATES

There were differences between sampling designs with respect to the precision of the various estimates. Coefficients of variation for the different methods ranged from 22% to 65% (Table 5). In general, index sampling was more precise than random sampling except for Trent River adults and French Creek jacks. Stratification did not produce significant gains in precision, perhaps due to the low number of samples in each stratum (only 2).

Area-Under-Curve Estimates

The precision of the AUC escapement estimates derived using simple random sampling was also dependent on sample size and survey unit size (Figs. 15 and 16). For all rivers, the precision of the estimates for both adults and jacks increased substantially with increasing sample size. The gain in precision due to survey unit length varied between systems. For **Black Creek** adults and jacks, there was very little effect of survey unit length (Fig. 15a and 16a). This may be due to the relatively homogeneous distribution of coho over the length of each 250 m unit, although they were highly aggregated in certain parts of the entire river. For **Trent River** adults and jacks, there was some gain in precision due to increasing survey unit length (Fig. 15b and 16b), perhaps because the distribution of coho in the Trent River was much more heterogeneous than in Black Creek. Similarly, in **French Creek** there was some gain in precision due to increased survey unit length but only for sample sizes of 10 and 12.

In general the results suggest that for Black Creek, greater increases in precision could be obtained by surveying more sites rather than increasing the length of the area surveyed at each site. For French Creek and the Trent River, increasing the length of survey units beyond 250 m and the number of units above 12, might result in more precise estimates. However, the

Table 3. Peak live abundance estimates of coho salmon derived from visual foot counts. Estimates were derived from counts of 250 m units for French and Black Creek, and from 200 m units for the Trent River. SRS is simple random sampling, SSRS is stratified random sampling, IS is index sampling, SIS is stratified index sampling, and MR is mark-recapture maximum likelihood escapement estimate. Numbers for SSRS and SIS correspond to the peaks on Figs. 5, 7 and 9.

	Sampling Design				
	SRS	IS	SSRS	SIS	MR
<u>Adults</u>					
Black Creek	821	1027	574	708	785
Trent River	190	522	86	692	909
French Creek	68	62	76	62	114
<u>Jacks</u>					
Black Creek	188	527	136	413	1071
Trent River	62	208	30	253	86
French Creek	131	108	149	116	255

Table 4. Peak live count estimates as a percentage of the mark-recapture estimate for adult and jack coho at Black Creek, Trent River and French Creek.

	Sampling Design			
	SRS	IS	SRSS	SIS
<u>Adults</u>				
Black Creek	104.6	73.1	130.8	90.2
Trent River	20.9	9.5	57.4	76.1
French Creek	59.3	66.8	54.7	54.5
<u>Jacks</u>				
Black Creek	17.6	12.7	49.2	38.6
Trent River	72.1	34.9	241.9	294.2
French Creek	51.4	58.4	42.4	45.5

Table 5. Coefficients of variation for the different survey designs, methods of calculation, streams, and maturity of fish. Estimates were derived from counts of 250 m units for French and Black creeks, and from 200 m units for the Trent River. SRS is simple random sampling, SSRS is stratified random sampling, IS is index sampling, and SIS is stratified index sampling.

	Sampling Design							
	Peak				AUC			
	SRS	SSRS	IS	SIS	SRS	SSRS	IS	SIS
<u>Adults</u>								
Black Creek	0.65	0.71	0.47	0.48	0.35	0.30	0.24	0.22
Trent River	0.31	0.51	0.27	0.33	0.38	0.34	0.27	0.27
French Creek	0.51	0.51	0.37	0.38	0.44	0.37	0.33	0.30
<u>Jacks</u>								
Black Creek	0.64	0.74	0.46	0.51	0.50	0.57	0.37	0.42
Trent River	0.40	0.57	0.33	0.37	0.28	0.25	0.26	0.24
French Creek	0.40	0.32	0.35	0.28	0.41	0.35	0.41	0.37

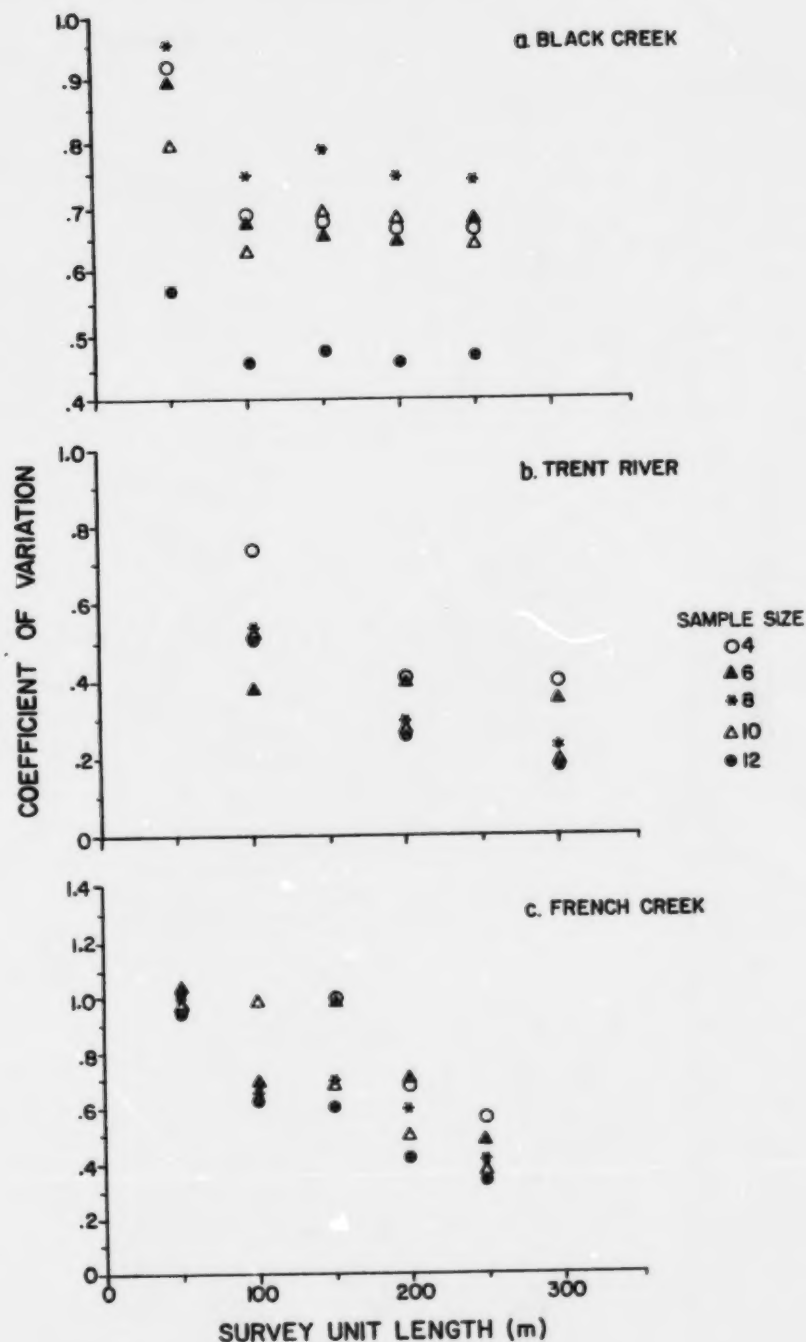


Fig. 15. Effect of sample size and survey unit length on the precision of AUC escapement estimates for adult coho derived using simple random sampling. In some cases, coefficients of variations are not presented for a particular unit length and sample size because zero fish were enumerated.

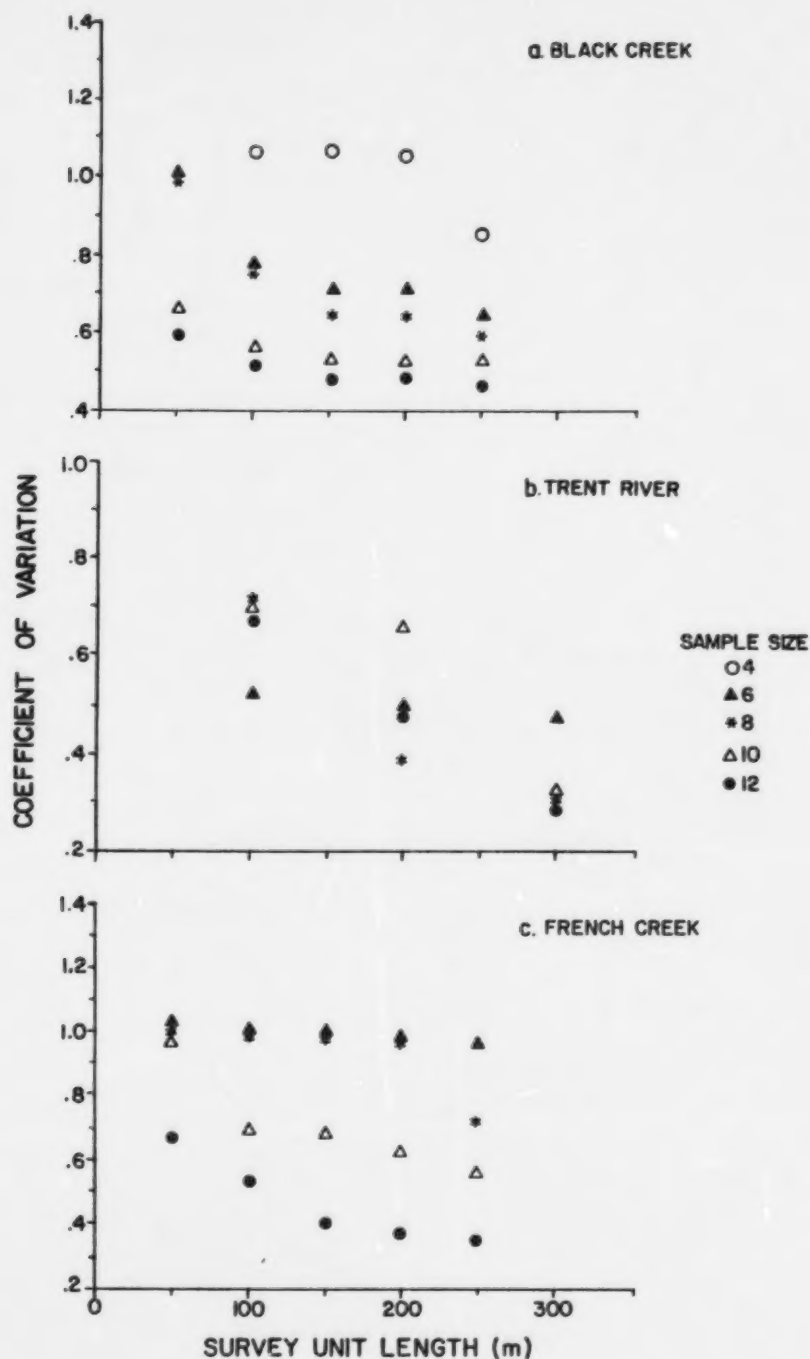


Fig. 16. Effect of sample size and survey unit length on the precision of AUC escapement estimates for jack coho derived using simple random sampling. In some cases, coefficients of variation are not presented for a particular unit length and sample size because zero fish were enumerated.

shapes of the curves in Fig. 15b and 15c suggest that the gain would not be great. We were not able to determine the point of significant diminishing returns of increased effort, but our simulation analyses (Appendix A) also indicate that survey unit lengths much larger than 250 m and sample sizes greater than 16 sites would not be of significant benefit in terms of precision.

Peak Live Counts

Peak counts were always less precise than AUC estimates (Table 5). However, the precision levels for the AUC estimates include variability in the survey life estimates. The estimates derived using peak live counts and AUC also includes the uncertainty in estimates of the efficiency of visual foot surveys.

EFFICIENCY OF VISUAL FOOT SURVEYS

Our average efficiency of observing adults and jacks using foot surveys at **Black Creek** was 54% and 31% respectively (Table 6). This indicates that the efficiency of observing jacks was 57% of the adult efficiency. This compares well with that estimate obtained by Solazzi (1984) who showed that efficiencies for jacks were 55% of efficiencies for adults. (The data used to determine these mean efficiencies are provided in Appendix D, Table 2.1-2.3).

Visual counts of adult coho using foot surveys in the **Trent River** were on average, 45% of snorkel counts. Assuming an overall average observer efficiency rate of 80% for snorkel surveys translates to an efficiency rating of approximately 35% for foot surveys at the Trent River (Table 6). Assuming the same ratio of jack efficiency to adult efficiency as for Black Creek (57%) led us to use an overall efficiency of 20% for jack coho in the Trent River escapements.

Insufficient data prevented us from estimating efficiency measures for using visual foot surveys at **French Creek**. We therefore assumed an efficiency rate of 69% for adults as determined by Johnston et al (1987). Again, assuming the same ratio of jack efficiency to adult efficiency for Black Creek led us to use an efficiency of 39% for French Creek jacks (Table 6).

Precision levels were low for all efficiency estimates (Table 6). This may be an artifact of sample size and large variability in the proportion of coho seen in different habitats and stream reaches.

There was substantial uncertainty associated with our efficiency during foot surveys which affected our AUC escapement estimates using SSRS (Figs. 17-18). As the efficiency of our visual foot surveys decreased, there was a proportional increase in the AUC escapement estimate. It should be noted that an incorrect efficiency estimate will bias the resulting escapement estimate. If the estimated efficiency is higher than the true efficiency, then the resulting escapement estimate will be underestimated. Conversely, an underestimate of efficiency will result in an overestimate of escapement.

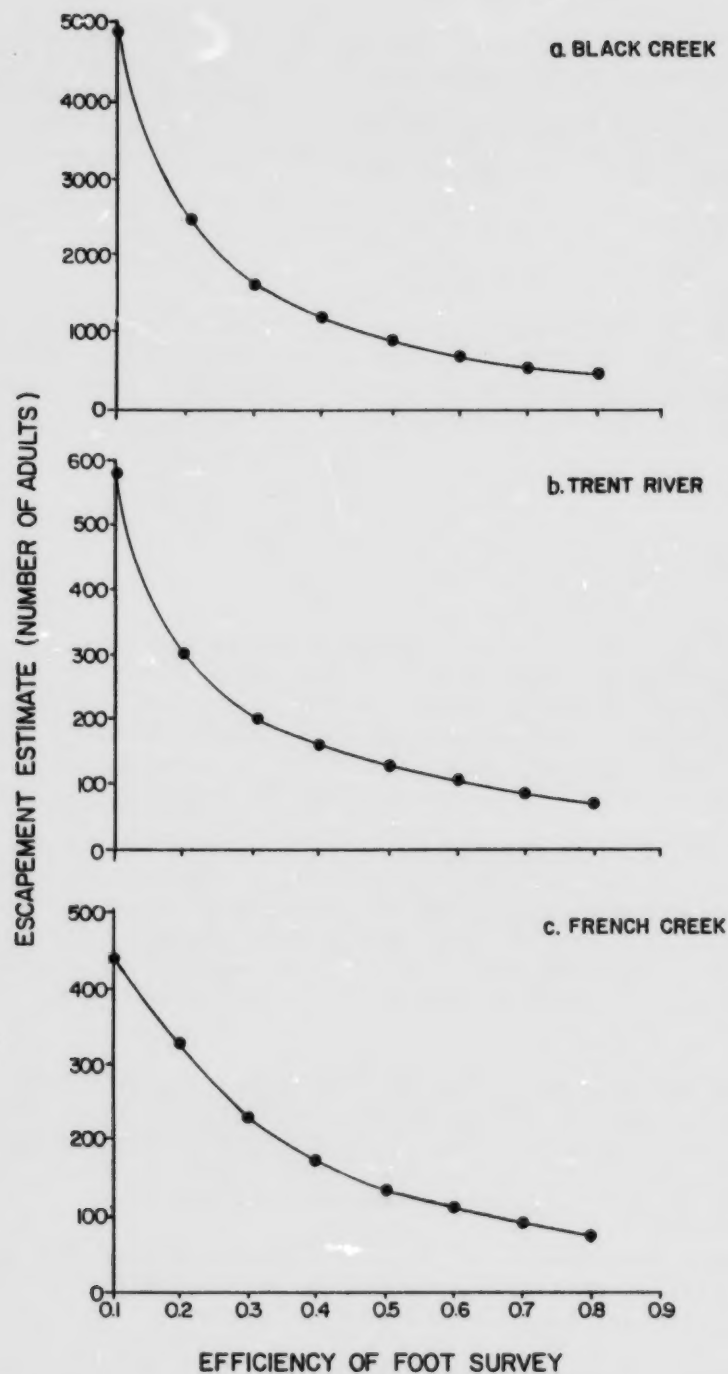


Fig. 17. Effect of the efficiency of visual foot surveys on the AUC escapement estimates for adult coho using stratified random sampling (SSRS).

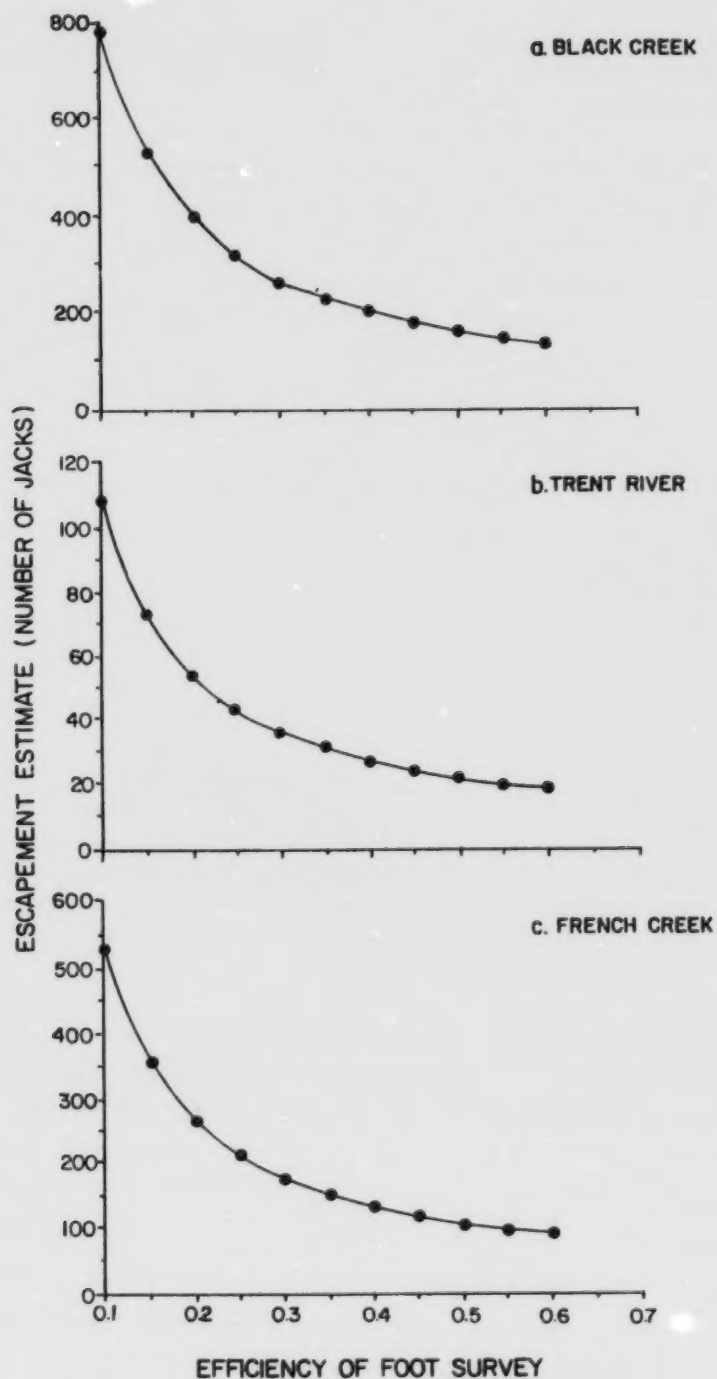


Fig. 18. Effect of the efficiency of visual foot surveys on the AUC escapement estimates for jack coho using stratified random sampling (SSRS).

Table 6. Efficiency of visual foot surveys for Black Creek, Trent River, French Creek. Standard deviations are in brackets. Efficiency values for jack coho are all 57% of the adult efficiency.

	Black n=16	Trent n=14	French n=11
Adults	0.54 ¹ (0.41)	0.35 ² (0.25)	0.69 ³ (0.25)
Jacks	0.31 ¹	0.20	0.39

¹Data in Appendix 2, Table 2.1, 2.2

²Data in Appendix 2, Table 2.3

³From Johnston et al. (1987)

SURVEY LIFE

Survey life values (Table 7) were determined for adult coho and the same values were assumed for jack coho in each system. Survey life for French Creek and Trent River coho was determined as the estimated period of freshwater residence since escapement estimates were expanded for the entire system. For Black Creek, where Northy Lake prevented complete sampling of the entire watershed, survey life was the average time adult spawners resided in sections of the creek above and below Northy Lake.

Table 7. Survey life in days for Black Creek, Trent River, and French Creek. Bold values are used to determine the AUC escapement estimates for each stream.

Survey Area	Estimation Method	Stream		
		Black	Trent	French
Entire Stream	Population Mortality Model	12.6	7.8	13.3
Section of Stream	Peterson mark-recapture survey data	8.0¹	11.0²	

¹Weighted mean survey life for 2 sections of Black Creek.

²Survey life for adult coho in upper reaches of Trent River.

The survey life values for the Trent River and Black Creek were based on the results from our Petersen tagging study. Tag depletion curves for the Trent River and the two survey areas of Black Creek are shown in Fig. 19 and 20. By integrating the curve and dividing by the number of tags applied, the mean survey life for the **Trent River** was determined to be 11.0 days (Table 7). Similarly, a weighted mean survey life for **Black Creek** (weighted mean survey life for upper and lower strata) was determined to be 8.0 days (Fig. 20b and c). Alternatively, we also determined a stream life of 10.3 for Black Creek by pooling all the tagging data over the entire stream (Fig. 20a). However, this value should be considered an underestimate of the true time spent live in the creek for the previously stated problems arising from Northy Lake. The lack of Petersen mark-recapture data for **French Creek** directed us to rely on the population mortality model for an estimate of coho stream life for that system.

The population mortality model was also used to provide an estimate of stream life for all three systems (Table 7). Escapement curves developed from the model are provided in Appendix E. It should be noted that discrepancies between stream life and survey life estimates were expected because each fish's residence time in a survey area is only a fraction of its total stream life. In instances where a substantial portion of the population may be inaccessible to surveyors for extended periods of time (e.g. Northy Lake on Black Creek), the stream life estimate derived from the mortality model should be larger than that derived using Petersen tag recoveries in the survey area. In the Trent River, the most likely explanation for the discrepancy between the model and mark-recapture estimates of stream life are: 1) the stream life for coho in the upper reaches of the Trent River is greater than for coho in other parts of the river, and/or 2) the mark-recapture population estimate for adult coho in the Trent River was an overestimate, hence the population mortality model would underestimate stream life.

The effect of uncertainty in the survey life value on AUC escapement estimates using stratified random sampling (SSRS) is illustrated for each system in Fig. 21. As was the case for the efficiency of visual foot surveys, a doubling of the value for survey life resulted in a halving of the escapement estimate.

ESTUARY COUNTS AS INDICES OF ESCAPEMENT

Fig. 22 shows the counts obtained using visual foot surveys at the estuary sites on Black Creek and French Creek. These counts are uncorrected for observer efficiency. Table 8 lists the peak live counts and AUC area estimates for these two sites. The peak abundance of adults and jacks occurred on 20 November for both Black Creek and French Creek. This was approximately 10 days prior to the peak abundance in the upstream portions of the creeks (Figs. 5 and 9). It should be noted that the total number of adult and jack coho seen during 5 hours of estuary observation at French Creek was more than 5 times the number observed during the subsequent 100 hours of foot surveys in the French Creek watershed. We expect to use these results in future studies to determine the suitability of estuary counts as an index of coho abundance.

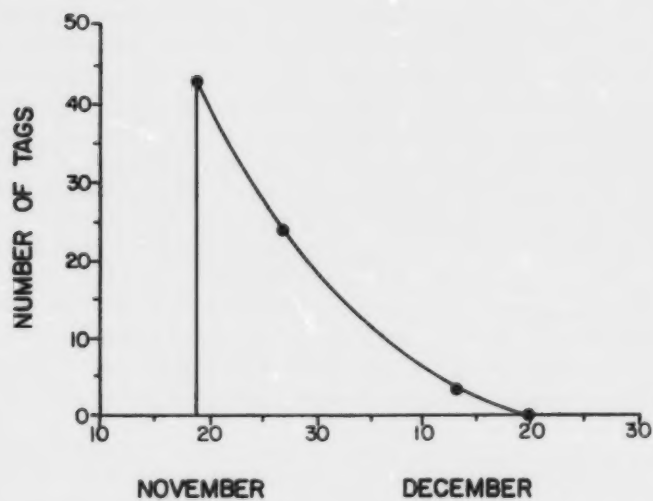


Fig. 19. Tag depletion curve for Trent River adult coho. Tags were applied on 19 November (indicated by vertical line). Number of tags were the estimated number of live fish with tags observed during float surveys.

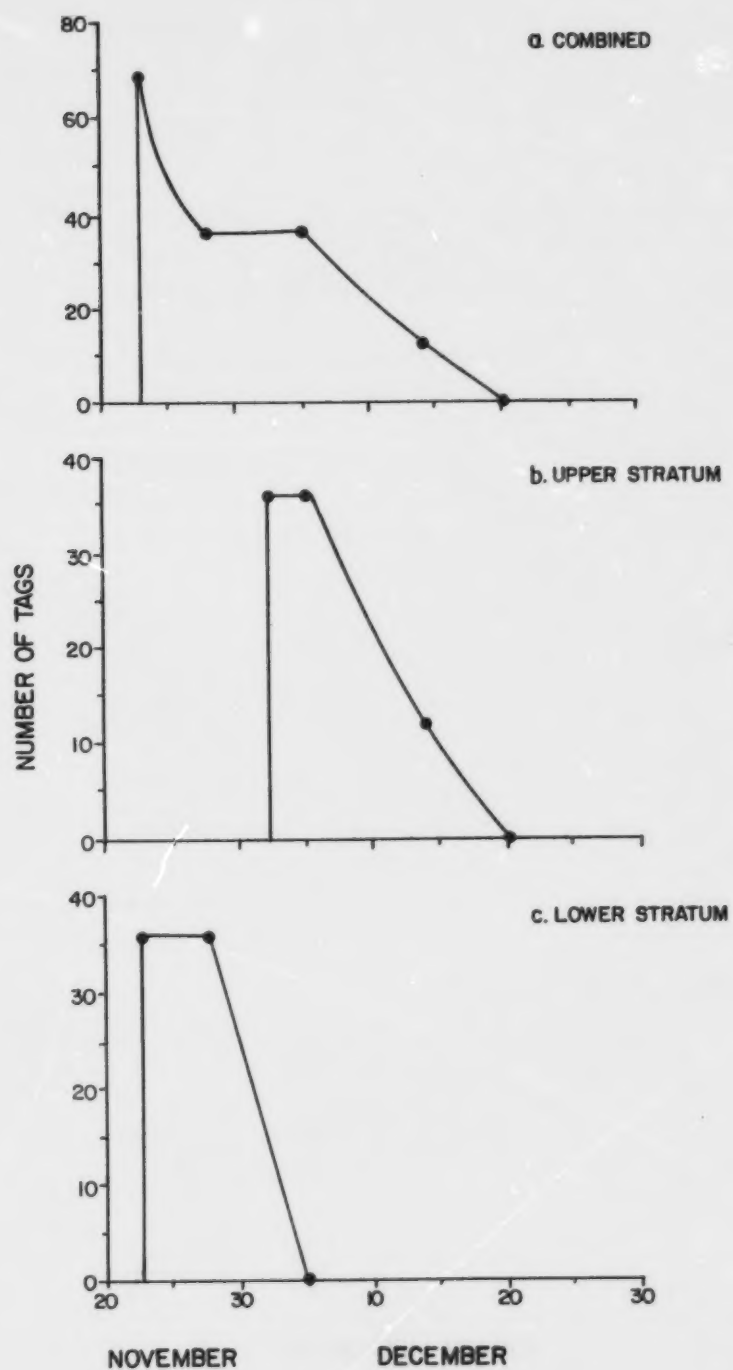


Fig. 20. Tag depletion curves for Black Creek adult coho. Vertical lines indicate date when tagged fish first entered the survey area.

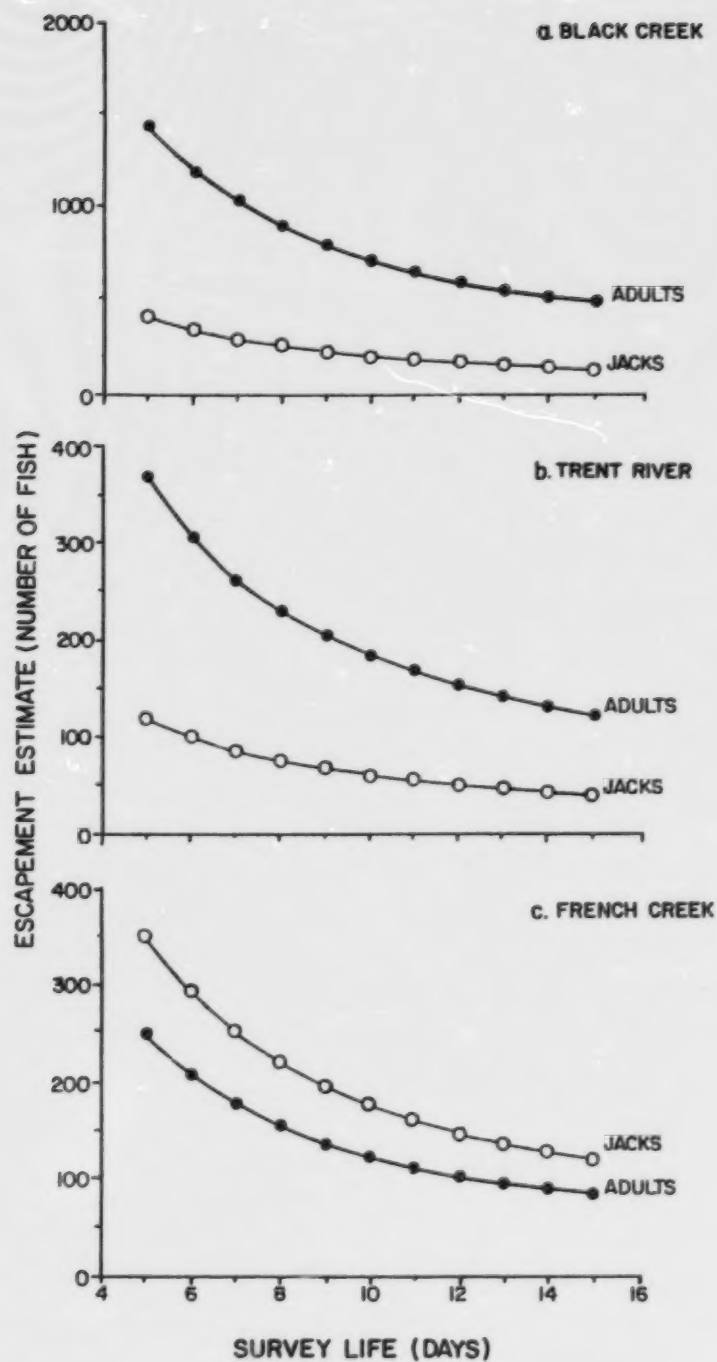


Fig. 21. Effect of survey life on the AUC escapement estimates for adult and jack coho using stratified random sampling (SSRS).

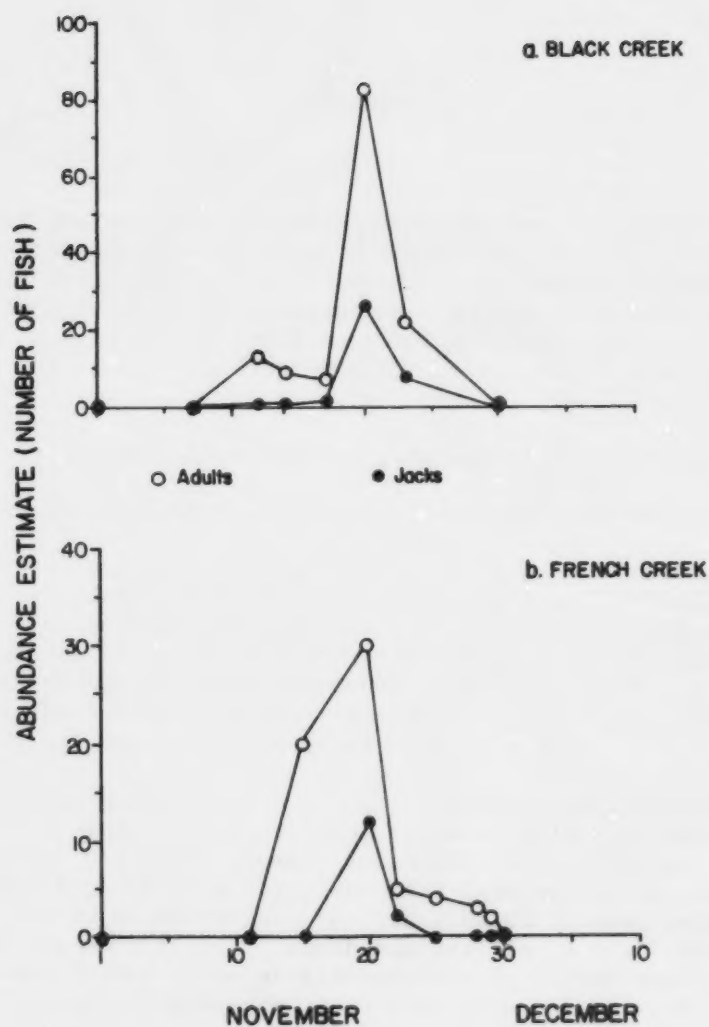


Fig. 22. Curves of abundance estimates for adult and jack coho counted at the estuary sites on Black Creek and French Creek. Counts are uncorrected for observer efficiency.

FRENCH CREEK INDEXING: 1986-87

AUC estimates and peak live counts for both years are shown in Table 9. Since 8 of our 12 index sites were also surveyed in 1986, observations can be made on the year to year variation in escapement estimates based on instream indexing. There appears to be some consistency in the peak live count expressed as a fraction of the mark-recapture estimate, as well as the AUC estimates. However, since stream life was not calculated for 1986 (the Little Qualicum stream life was used), a direct comparison of the AUC estimates was not made.

DISCUSSION

In this study, we compared simple random sampling and index sampling (stratified and unstratified) techniques to estimate the escapement of coho salmon to three streams on Vancouver Island: Black Creek, Trent River, and French Creek. These streams differ substantially in terms of their biophysical characteristics, hydrology, and the instream distribution of coho salmon. Our primary objectives were to determine the appropriate sampling design and level of effort required to:

1. estimate total coho escapement in each stream every year, and
2. produce a reliable index of escapement to be used over several years.

We found that the accuracy of escapement estimates for each of the sampling designs and the level of effort required for a single year estimate (1987) varied depending on the system and population attributes. Since this is only the second year of study on French Creek and the first on the other two streams, we were not able to address the second point mentioned above in any detail. One of the long-term goals of this research is to evaluate the use of index sites to generate indices of coho escapement in these three systems.

Theoretically, escapement estimates derived using random sites should be unbiased provided sufficient sampling effort is used (i.e., large sample size and/or long sample units). With small sample sizes and short survey units, the possibility exists that too many sites will be in areas of low or high fish abundance, leading to an under- or over-estimate of the actual escapement. At the Trent River, the abundance of adult coho was very patchy and a disproportionate number of our randomly selected survey sites were in low abundance areas. As a consequence, our adult escapement estimate using stratified random sampling was very low (18% of the mark-recapture estimate). At Black Creek and French Creek, adult coho were more uniformly distributed within strata, and hence the estimates using stratified random sampling in these two streams were more accurate (113% and 83% of the mark-recapture estimate, respectively).

Table 8. AUC escapement estimates and peak live counts of adult and jack coho based on estuary surveys at French Creek and Black Creek. Estimates are uncorrected for observer efficiency. AUC estimates are in fish-days.

Site	AUC		Peak live	
	Adults	Jacks	Adults	Jacks
Black Creek, El	447	117	83	26
French Creek, El	228	57	30	12

Table 9. French Creek AUC escapement estimates and peak live counts for adult coho using an indexing design (IS) with the same 8 index sites in 1986 and 1987. See Johnston et al. (1987) for original data from 1986. Estimates were derived from counts of 250 m sample units in 1987 and from 100, 200, and 400 m sample units in 1986. Counts from 1986 adjusted for sample unit size (250 m) for comparative purposes. Count data are presented in Appendix F.

Year	AUC	Peak live	MR	AUC/MR	Peak/MR
1986	370	313	1153	0.32	0.27
1987	42	25	114	0.37	0.22

Carefully chosen index sites can provide an accurate estimate of the escapement when the fish are highly aggregated, as was the case at the Trent River. Hence, with prior knowledge of the distribution of adult coho (from snorkel surveys), we were able to select index sites that provided a reasonable estimate of the population of coho (80% of mark-recapture estimate using stratified index sampling). At Black Creek and French Creek, index sites were selected on the basis of habitat types and the expected utilization of those areas by coho. The success of this selection process was different for these two systems. At Black Creek, poor access to the creek limited the potential number of areas from which to choose index sites. Coincidentally, many of these accessible areas consisted of spawning areas. Hence, many of our index sites on Black Creek were located in high fish abundance areas, and our escapement estimate using stratified index sampling was high (191% of the mark-recapture estimate). At French Creek, our selection of index sites was not constrained by access, and we were better able to select index sites in a variety of habitat types. Our escapement estimate for adult coho in the system using stratified index sampling was 65% of the mark-recapture estimates, despite the extreme low abundance of fish in 1987.

The success of using index sites to estimate the total escapement to a particular stream is dependent on how well the sites are selected commensurate with the distribution of fish in the stream. The instream distribution of fish is usually not known but is predicted based on the habitat qualities of the stream. Thus, escapement estimates derived using sites selected in this manner are highly susceptible to error since habitat quality and the ensuing spawner distribution can change substantially from year to year. Because of this potential for bias we caution against using index sites to generate estimates of total escapements for coho in streams where the distribution of fish is difficult to predict.

If simple trends in escapements of coho are desired, then there appears to be some legitimacy in using carefully selected index sites as estimates of coho abundance, provided that the abundance of coho in these sites relative to the total abundance in the river is known or does not change drastically from year to year (Beidler and Nickelson 1980).

The precision of escapement estimates derived by the different sampling designs varied, with coefficients of variation ranging from 22% to 57% for AUC escapement estimates. Index sampling generally produced AUC estimates that were more precise than random sampling. This is not surprising since the index sites were chosen in accordance with the predicted distribution of coho for Black Creek and French Creek, and the actual distribution of coho for the Trent River. The random sites, by the very nature of their selection were more likely to be situated in areas of varying abundance. Stratification did not produce significant gains in precision. This occurred because coho in these three systems were aggregated between strata and within strata. Our sample size per stratum was also small (2 sites per stratum), which contributed to these results.

We evaluated the level of effort required to produce accurate and precise AUC estimates using random sampling. We found that gains in precision and accuracy could be obtained by increasing the length and number of sites. This is consistent with the results of Johnston et al. (1987) who found that the precision of escapement estimates at French Creek increased with survey

lengths from 100 m to 200 m with little gain in precision for 400 m units. We observed that the appropriate level of effort varied between systems. At Black Creek, where the coho seem to congregate in relatively large spawning areas, a large number of samples sites (>12) of 100 m is required to produce relatively accurate and precise AUC estimates. On the other hand, at French Creek and the Trent River, where coho are more sparsely distributed and aggregated in small habitat units (typically pools 25 m long), it is necessary to patrol longer survey units to maximize accuracy and precision.

A major objective in this study was to determine the effect of varying sampling effort on AUC estimates using random sampling. To our knowledge, this is the only study, with the exception of Johnston et al. (1987), to specifically address this question with respect to salmon escapement estimates. In future surveys we plan to evaluate the level of effort required to produce reliable indices of coho escapement using index sites. Our preliminary results for random sampling suggest that surveys of 12 index sites per system, each 250 m long, is sufficient to produce adequate indices of coho abundance. It remains to be determined how the number of spawners in the stream affects the level and allocation of survey effort. It is important to assess the required amount of effort, given the constraints of estimating coho escapement on a coast-wide basis in British Columbia. Coho escapement levels in French Creek in 1987 were considerably lower than previous years (one tenth of the 1986 level). We hope to evaluate the various sampling designs over a wide range of escapement levels.

In addition to the above, we examined the uncertainty in the escapement estimates due to: 1) the efficiency of the visual foot surveys; and 2) the survey life value used in the AUC estimate. We found that the efficiency of visual foot surveys is an important factor influencing the accuracy and precision of escapement estimates. We observed between 35% and 69% of adult coho in the three systems and between 20% and 41% of jack coho. These estimates varied significantly between systems. By comparison, Solazzi (1984) observed, on average, 75.5% of adult coho and 47.8% of jack coho in Oregon streams over a 2 year period. Our efficiency of observing coho using foot surveys was highest at French Creek and Black Creek (69% and 54% for adult coho, respectively) and considerably lower at the Trent River (35% for adults). This is because coho were more easily observed when actually spawning in the former two streams. At Trent River, coho were never observed spawning and seemed to remain in deep pools or under debris jams for the duration of the survey period. These fish probably spawned in small pockets of gravel or shale at the edge of the protective habitat.

In the calculation of the escapement estimates we did not account for the uncertainty associated with our estimates of observer efficiency. This uncertainty should be incorporated in the escapement estimation. It is important that foot survey efficiency be estimated as accurately and precisely as possible on a system by system basis.

The AUC estimate of escapement requires either an estimate of survey life to convert the number of fish-days to the number of fish or the comparison of the estimate of the number of fish-days to a base year index. However, Flint (1984) showed that estimates varied widely depending on which base year was used. Hence, the use of an appropriate value for survey life is desirable.

The appropriate interpretation of survey life may be determined by stream attributes. We counted fish at locations spread over the entire length of each system. We then extrapolated these counts to yield an estimate of the number of fish days (survey life) in each system upstream of the counting fences. Therefore, for each stream, survey life should be approximated by the average number of days coho spend alive in the stream (stream life). However, in Black Creek we could not survey or estimate the number of coho residing in Northy Lake, and hence our escapement estimates were only representative of the fish present in the rest of the system. This is graphically illustrated in Fig. 23 which shows the escapement curve for Black Creek adult coho derived using the population mortality model (adapted from Fig. E.1, Appendix E) and the curve derived using stratified random sampling (adapted from Fig. 5a). The fish that were unaccounted for in our foot surveys (hatched area) may have been holding in Northy Lake and adjacent swamp areas below the spawning grounds.

Since the area under curve 2 is divided by the number of days fish spent in the entire stream (stream life), the resulting escapement estimate may underestimate the actual escapement. To prevent this, it was necessary to base our estimates on the time coho spent in the sections below and above Northy Lake. We highlight this important concept in the use of survey life in AUC escapement estimates because it has often been inappropriately used (Perrin and Irvine 1988). If fish days are estimated for only part of a watershed, survey life must be the time spent by fish in that part of the watershed. If fish days refer to the whole watershed, survey life must be the time spent in the whole watershed (stream life).

Our results indicate that stream life is highly variable between systems and that AUC escapement estimates are highly sensitive to it. Doubling estimates of survey life results in a 50% reduction in the AUC estimate. Our sensitivity analyses also indicate that uncertainty about a large survey life is less critical than uncertainty about a small survey life. If survey life varies between years, as suggested by Crone and Bond (1976) and van den Berghe and Gross (1986), then average survey life must be determined each year.

The levels of precision and accuracy obtained for our escapement estimates compare favourably to other salmon escapement estimates derived using visual foot survey techniques (Cousens et al. 1982). Our results indicate that it is possible to obtain accurate estimates of coho at Black Creek and French Creek using rigorous visual foot survey techniques. At Trent River, estimating coho abundance using visual foot surveys is much more difficult because of the size of the river and the instream behaviour of coho. However, snorkel surveys were successful at Trent River and allowed us to select adequate index sites for future surveys.

These results are for only one year of study in three separate streams. To adequately evaluate the use of instream indexing and the sampling designs tested here, several years of study are required. The next stage of this research is to test for the repeatability of our 1987 results. The effort required to produce accurate and precise escapement estimates on an annual basis is substantial. The use of instream indexing to produce indices of escapement for examining trends may be cost effective. An analysis of the gains in precision and accuracy of escapement estimates using various approaches, and the costs of achieving these levels of accuracy would be useful. It may be that the most cost effective procedure for estimating coho

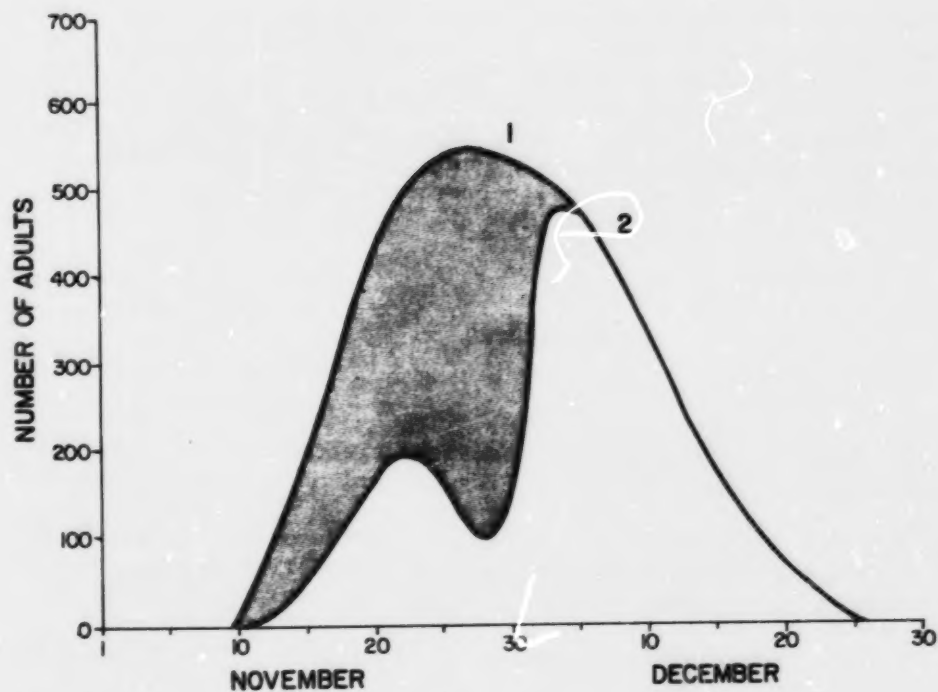


Fig. 23. Adult escapement levels through time at Black Creek. Curve 1 is adapted from Fig. E.1 in Appendix E. Curve 2 is adapted from Fig. 5a (SSRS curve). The hatched area indicates the number of fish-days based on the population mortality model that exceed the estimate derived using visual foot surveys of randomly selected sites.

returns to small streams is to systematically survey only estuary sites, which are highly accessible and where many fish can be observed in a short time period. This stream indexing research should ultimately assist in determining cost-effective approaches that can be used by workers in the field to estimate coho escapement with acceptable accuracy and precision.

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APPENDIX A

**Methods and Results of Simulation Model Used to
Determine Optimum Sampling Effort for Each System Considering
Accuracy and Precision Levels Desired for AUC Escapement Estimates**

INTRODUCTION

The proper design of a study to enumerate coho salmon escapements to coastal streams should identify the number of sites and length of each sample site such that the relationship between these variables and the resulting precision and accuracy of escapement estimates can be determined. The sampling design must take into consideration the numbers and distribution of fish over time as well as logistic and financial constraints. Past observations of fish at Black Creek, Trent River and French Creek indicated that adult coho were not uniformly distributed throughout these streams (Labelle in prep). Such facts were taken into consideration during computer simulations aimed at determining appropriate sampling regimes for adult coho in the study streams. We used this model to evaluate the precision and accuracy of escapement estimates derived from different sampling designs and levels of effort. The results of these simulations were compared with those which could be empirically estimated for a uniform distribution of fish using procedures outlined in Elliott (1977). Using this model we determined, a priori, the optimum survey unit length and number of sites to survey at French Creek, Black Creek, and the Trent River.

SIMULATION MODEL

The first task in the development of the simulation model was to simulate the distribution of live coho within each stream over a 50 day period. The total number of live coho in each stream at any point in time $FISH(t)$ was determined by the following equation:

$$FISH(t+1) = FISH(t) + COUNT(t) - DEAD(t)$$

where $COUNT(t)$ is the number of coho counted at the fence on day t and $DEAD(t)$ is the number of coho in the stream that died on day t . The number of coho counted at the fence on each day was equal to the observed 1985 fence counts at Black Creek, Trent River and French Creek expanded such that the total return for the first 30 days of each run was 5460, 1340, and 1260 coho, respectively. The number of coho that die each day was based on two assumptions: 1) few fish die during the first two days they are in the stream, and most fish die before their 31st day in the stream; and 2) the die-off is binomially distributed over days 21 through 30. These assumptions are consistent with observations of coho distribution in the three systems during 1985 and 1986.

The distributing of the live fish $FISH(t)$ throughout the stream was a four step process.

1. Each stream was divided in two sections of equal length. The proportion of $FISH(t)$ allocated to the sections each day changed at five day intervals so that the majority of the fish were in Section 1 (lower reaches or holding areas) early in the season and in Section 2 (upper reaches or spawning areas) later in the season.

2. Each section was divided into 100 m units. The number of fish per unit was equal to the mean density for the section times a random number drawn from a log normal distribution with a standard error of 1.2. Therefore, for a mean of 6 fish/unit roughly 95% of the values would be between 4 and 8 fish/unit.
3. The fish were aggregated by randomly selecting 30% of the 100 m units in each section and reallocating all the fish in the unit to an adjacent unit. Therefore, 30% of the 100 m units would have no fish, 30% would have roughly twice the mean density of coho and 40% would have approximately the mean density of coho.
4. Finally, each unit was divided into two equal sub-units with the number of fish per 50 m sub-unit equal to the mean density for the 100 m unit, times a random number drawn from a log normal distribution with a standard error of 1.2.

This process was repeated each day so the number of fish in a specific unit could be substantially different on each survey day even if the total number of fish in the stream remained the same.

Once the number and distribution of fish was determined, the total number of live fish in the whole stream was calculated and accumulated over the 50 day simulation. This cumulative number of live fish-days was then divided by the known mean stream life for the simulated coho population to compute the total escapement to each stream. The computed escapement was always slightly different from the total return because of the frequent adjustments using random numbers. The numbers of coho per area/time stratum in each stream were subsequently used to evaluate a wide variety of sampling designs.

The sampling sub-model was designed so the user could specify the stream, the number of samples per stratum, and three fish observation goals for inverse sampling or direct sampling. Inverse sampling means that the length of the area surveys is determined by the number of fish seen (i.e., surveyors walk until they see a specified number of fish) (Ricker 1975). In direct sampling the length of each survey is determined in advance. The user was also requested to specify the number of Monte Carlo iterations for each run. Sampling was stratified by day and stream section, and all simulations involved seven pairs of sampling days during which stream section 1 was sampled a specified number of times on the first day and stream section 2 was sampled the same number of times on the second day. Each stream was sampled two days each week. The starting location for each survey was randomly selected from the 100 m units in each stream section, and the number of fish observed in each sub-unit surveyed was equal to the actual number of fish times an observer efficiency of 70% times a random number drawn from a log normal distribution with a mean of 0.7 and a standard error of 0.08 (Johnston et al. 1987). The model calculated the fish density for each sampling goal, and each simulated survey continued until the number of fish observed or distance covered was equal to the maximum sampling goal.

Once the sampling was completed, the mean, variance, and standard error for coho density estimates was determined as well as the total survey length for each two day interval. These values were accumulated for all Monte Carlo iterations. These values were then divided by the number of iterations,

used to estimate the number of live fish in the stream for each 2 day interval along with lower and upper bounds of the 95% confidence interval for each estimate. An interpolation procedure was used to convert these point estimates into estimates of the number of live fish in the stream each day. These were summed and divided by the stream life to produce the mean and bounds for the total escapement estimate. The precision and accuracy associated with various sampling procedures were used to generate the sampling nomograms presented below.

RESULTS

Our first observation was that the escapement estimates derived from inverse sampling, as conducted in the simulation model, were both less precise and less accurate than the estimates derived from direct sampling. The reasons for this are as follows:

1. Observation goals of a set number of fish will either reduce the number of samples when goals are high and fish densities are low; or reduce the area surveyed when goals are low and fish densities are high. These reductions tend to make the escapement estimates less precise than those derived from direct sampling procedures.
2. Observing a given number of fish tends to produce biased estimates for aggregated distributions of fish. Biases occur when a surveyor needs fewer fish to fulfill the observation goal than are in pool or small areas. If the observer ends the survey and records the total number of fish in the pool, the resulting estimates are positively biased. If the observer ends the survey and records the observation goal as the number of fish seen the resulting estimates are negatively biased. Any other adjustments to the number of fish seen or distance surveyed are subjective.

Therefore, we used direct rather than inverse sampling to devise preliminary estimates of the number of samples and distance to be surveyed per sample using the sampling nomograms for each study stream.

Figs. A.1 through A.3 present the results of 36 sampling simulations for the three study area streams. These figures clearly show that the precision of the AUC estimate improves with increased numbers of samples (N) and the distance surveyed per sample (DPS). However, incremental improvements to precision decrease rapidly when sample size exceeds 10 per week and distance surveyed exceeds 200 m per sample. The 1000 m, 2000 m, 3000 m, and 4000 m lines show how precision improves with the total distance surveyed (N times DPS). The area to the left of the black dot and above the 12 sample contour shows the portion of the monogram that could be determined for each stream from actual data if 12 samples of at least 250 m are surveyed in each stream seven times over the duration of the run. The actual precision of the resulting estimates may be more or less than the simulated values depending on the actual distribution of fish. If fish abundance in the 250 m surveys are less variable between sampling days than those in the simulation model, escapement estimates will be more precise. This fact is exemplified by the nomogram (Fig. A.4) for sampling from a uniform distribution of 1000 fish in French Creek (i.e., 6.25 fish per 100 m unit). The lines plotted in Fig. A.4 were derived from

equations for sampling from a Poisson distribution presented in Elliott (1977 p. 130). This nomogram suggests that the 95% confidence intervals for twelve 250 m surveys per stream per 2 day period would be $\pm 20\%$ of the population estimate for each 2 day period, rather than $\pm 39\%$ of the comparable estimate for simulated sampling from an aggregated distribution of fish. The precision of the population estimates for each two-day period depends on the density of fish in the stream during the survey period. The comparable precision of the AUC estimate for French Creek, 29% in Fig. A.4, was less than 39% because the simulated densities were as high as 8.2 fish per 100 m unit during some of the sampling periods.

Fig. A.5 provides a rough indication of the relationship between accuracy and the distance surveyed each day for French Creek simulations. The reader should note that each of the points in Fig. A.5 was derived from only 20 Monte Carlo iterations and that none of the estimates were significantly different from the true escapement. More than 100 iterations would be required to determine the exact relationship between accuracy and the distance surveyed for the simulated coho population.

The results of these simulations led us to design a sampling program for each system based on surveying a minimum of 12 random sites and 12 index sites, with each sample unit being 250 m long. As mentioned earlier, this allowed us to examine different sample sizes of less than 12 per system and unit lengths less than 250 m (see Fig. A.1, A.2 and A.3).

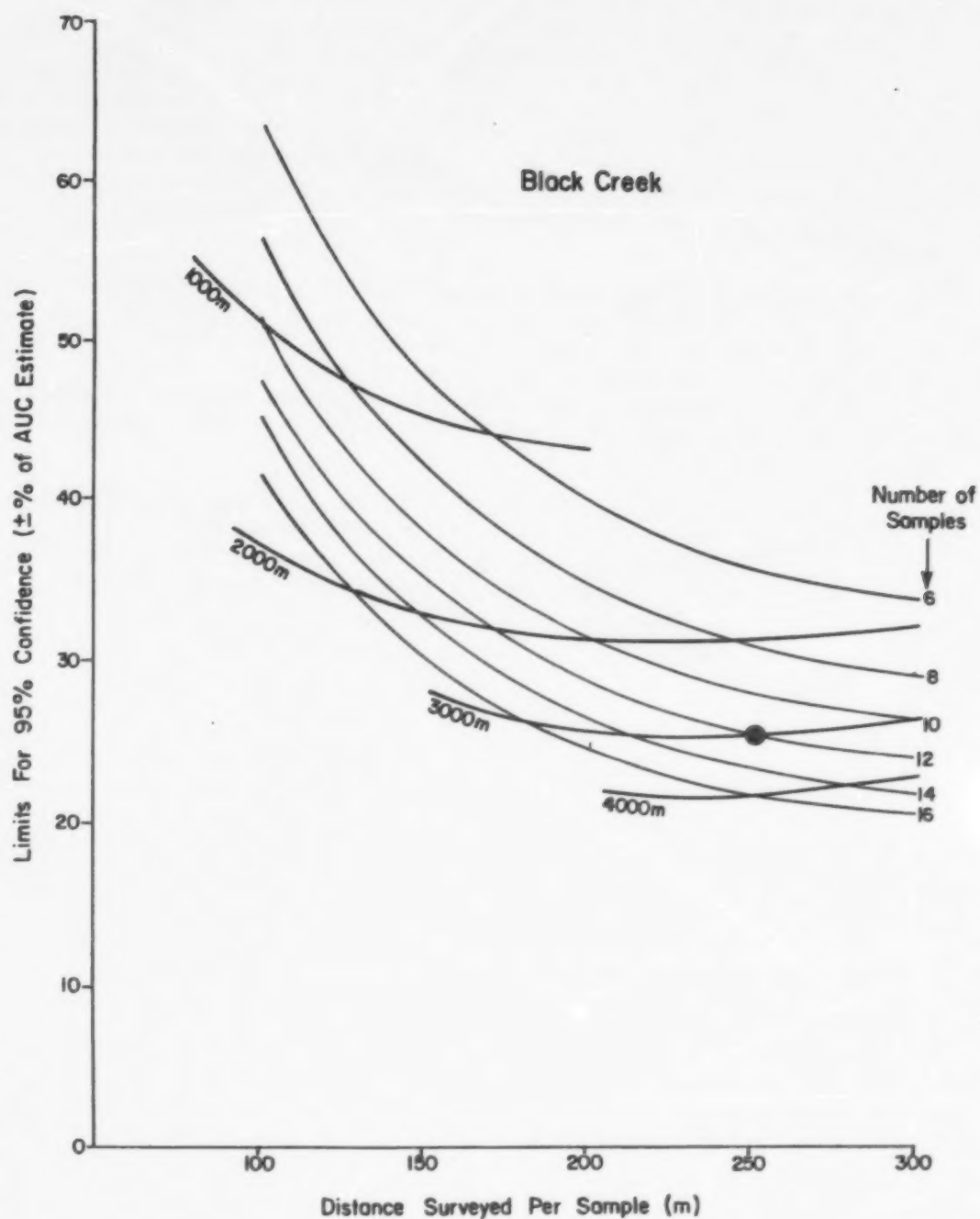


Fig. A.1 Relationship between precision of AUC escapement estimate and sampling effort derived from simulated sampling of the 1985 coho returns to Black Creek. The black dot indicates the recommended sampling effort of twelve 250 m surveys per week. The 1000-4000 m lines show how precision improves with the total distance surveyed each week.

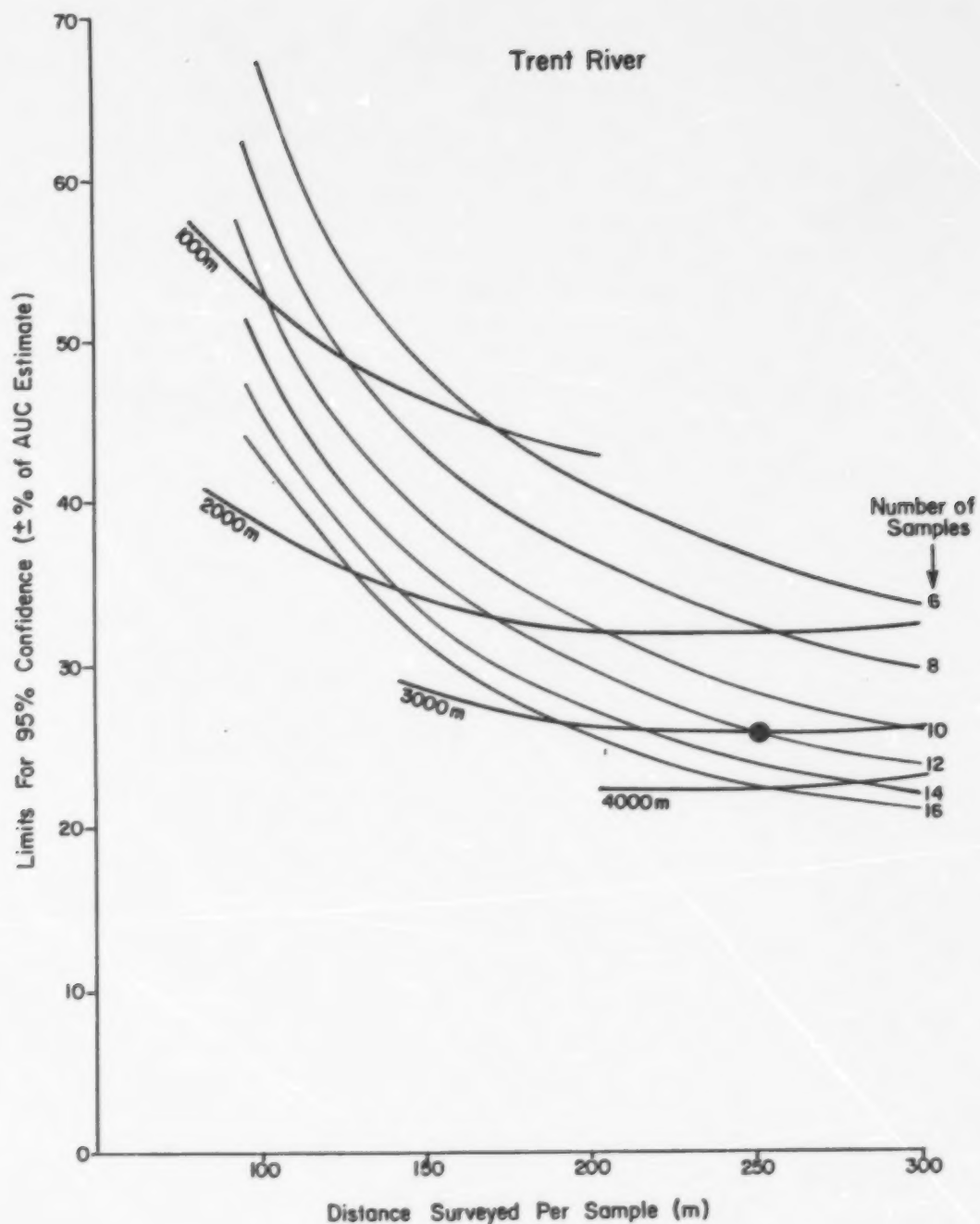


Fig. A.2 Relationship between precision of AUC escapement estimate and sampling effort derived from simulated sampling of the 1985 coho returns to Trent River. The black dot indicates the recommended sampling effort of twelve 250 m surveys per week. The 1000-4000 m lines show how precision improves with the total distance surveyed each week.

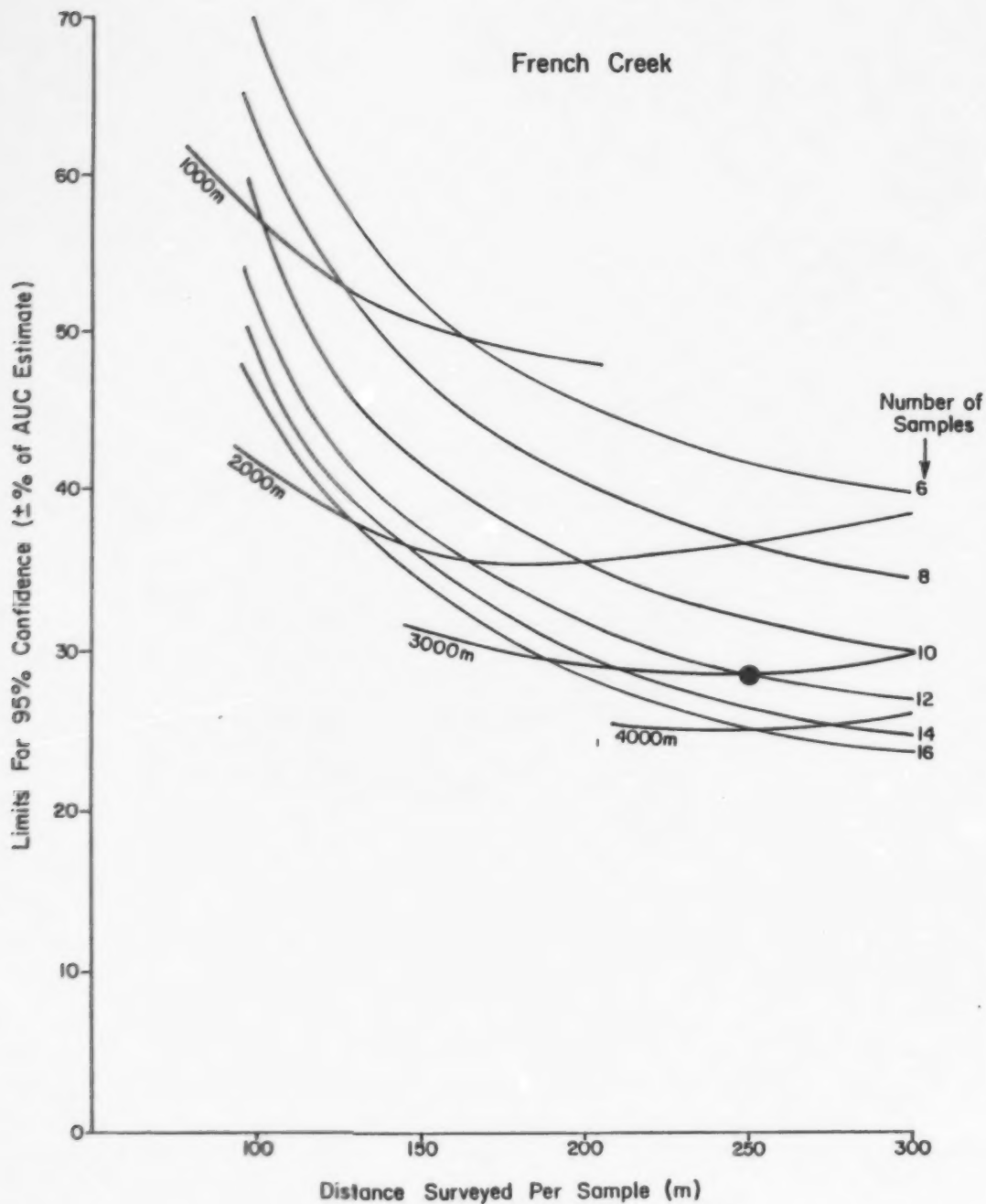


Fig. A.3 Relationship between precision of AUC escapement estimate and sampling effort derived from simulated sampling of the 1985 coho returns to French Creek. The black dot indicates the recommended sampling effort of twelve 250 m surveys per week. The 1000-4000 m lines show how precision improves with the total distance surveyed each week.

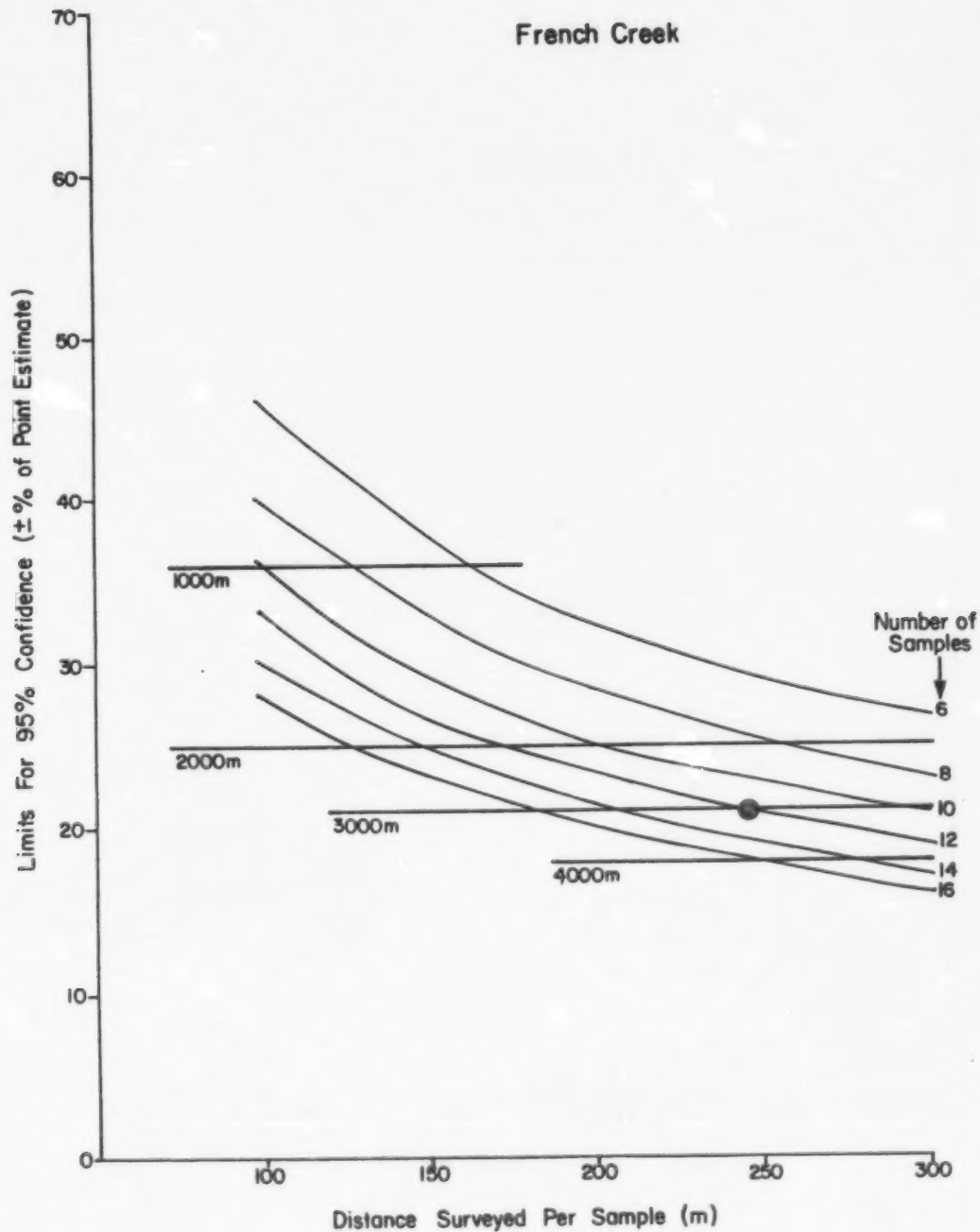


Fig. A.4 Relationship between precision of a point escapement estimate and sampling effort derived from equations for sampling from a Poisson distribution presented in Elliott (1977). The basis for this nomogram is the assumption that the 1000 fish are uniformly distributed over the 16 km of French Creek.

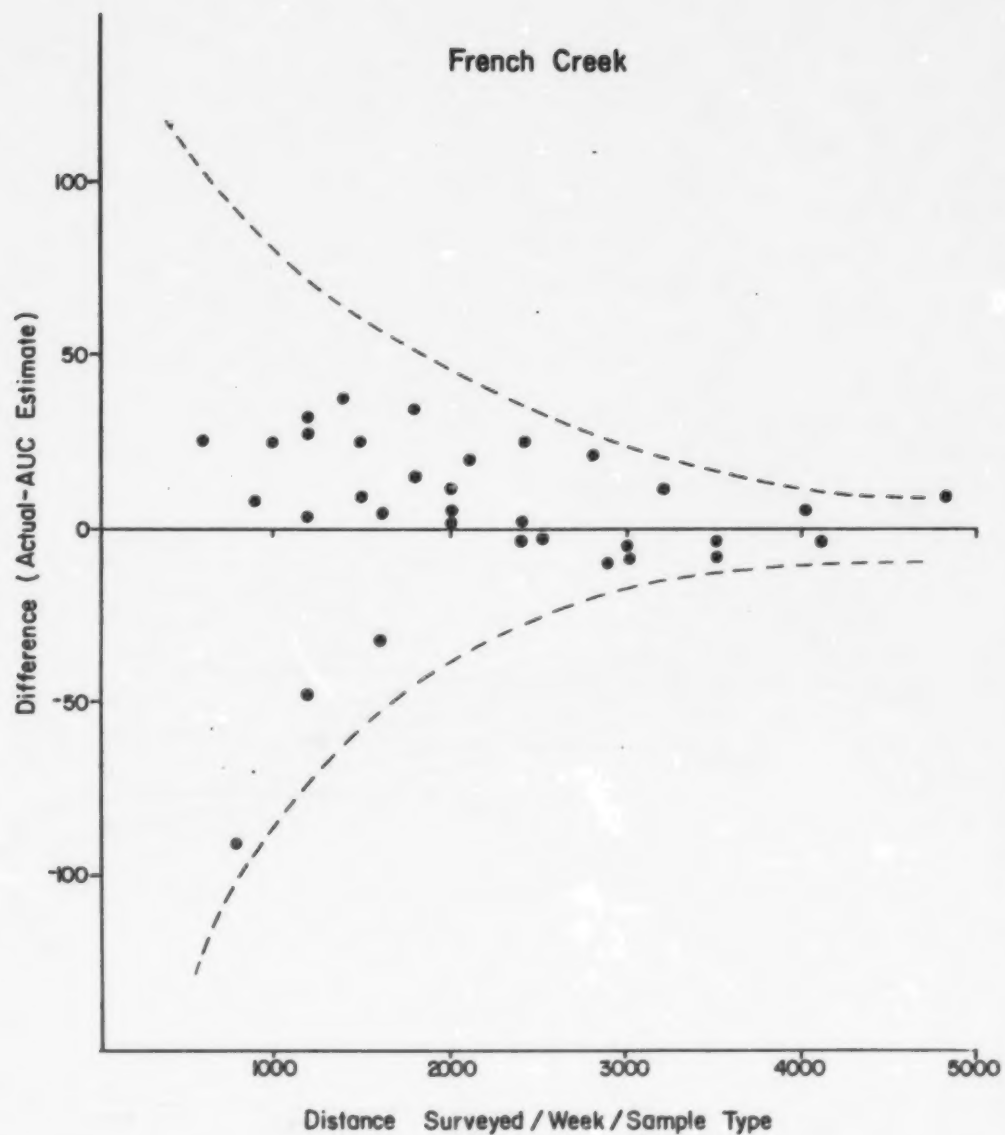


Fig. A.5 Relationship between the accuracy of the AUC escapement estimate and the total distance surveyed per week derived from simulated sampling of the 1985 coho returns to French Creek. The difference between the actual escapement and the AUC estimate is small when compared with the confidence interval for each estimate.

APPENDIX B

**Biophysical Characteristics of Index Sites
Used for Visual Foot Surveys in Each Stream**

Table B.1. Biophysical characteristics for index sites, excluding estuary site, in Black Creek.

Site Number	50m Interval	Mean Channel Width (m)	Habitat Composition			Substrate Composition			Value ¹ for Spawning	
			% pool	% riffle	% run	% fines	% gravel	% bedrock		
2	0-050	15	10	80	10	0	60	40	0	1.0
2	50-100	12	15	60	25	0	50	50	0	1.0
2	100-150	11	10	20	70	10	20	70	0	0.5
2	150-200	14	20	60	20	10	50	40	0	1.0
2	200-250	12	20	60	20	5	65	30	0	1.5
3	0-050	10	10	70	20	5	80	15	0	2.0
3	50-100	12	50	30	20	5	50	45	0	1.0
3	100-150	12	40	30	30	5	50	45	0	1.0
3	150-200	9	10	80	10	10	20	70	0	0.5
3	200-250	10	0	90	10	5	20	75	0	0.0
4	0-050	5	0	100	0	5	30	35	30	0.5
4	50-100	5	0	70	30	5	20	60	15	0.0
4	100-150	5	0	70	30	10	35	15	30	1.0
4	150-200	6	0	50	50	10	60	20	10	2.0
4	200-250	5	0	50	50	10	45	25	20	1.5
5	0-050	5	40	40	20	10	80	10	0	1.5
5	50-000	5	5	15	80	5	85	10	0	2.0
5	100-150	4	25	50	25	5	45	50	0	1.0
5	150-200	5	5	15	80	5	50	45	0	1.0
5	200-250	6	0	55	45	5	55	40	0	1.0
6	0-050	4	0	0	100	25	35	40	0	0.5
6	50-100	4	0	0	100	30	30	40	0	0.5
6	100-150	5	0	0	100	20	50	30	0	1.0
6	150-200	5	0	0	100	40	30	30	0	0.0
6	200-250	5	0	0	100	40	30	30	0	0.0

10.0 = poor, 1.0 = fair, 2.0 = good.

Table B.1. (cont.)

Site Number	50m Interval	Mean Channel Width (m)	Habitat Composition			Substrate Composition			Value for Spawning
			% pool	% riffle	% run	% fines	% gravel	% bedrock	
7	0-050	3	45	10	45	65	35	0	0.0
7	50-100	3	20	50	30	65	35	0	1.0
7	100-150	3	35	30	35	65	35	0	1.0
7	150-200	3	20	50	30	70	30	0	1.0
7	200-250	3	25	45	30	70	30	0	0.5
8	0-050	4	0	0	100	90	10	0	0.0
8	50-100	4	0	0	100	95	5	0	0.0
8	100-150	4	20	0	80	95	5	0	0.0
8	150-200	4	0	0	100	95	5	0	0.0
8	200-250	4	0	10	90	90	10	0	0.0
9	0-050	6	0	0	100	95	5	0	0.0
9	50-100	7	0	0	100	95	5	0	0.0
9	100-150	6	0	0	100	95	5	0	0.0
9	150-200	5	0	0	100	95	5	0	0.0
9	200-250	5	0	0	100	95	5	0	0.0
10	0-050	3	0	0	100	90	10	0	0.0
10	50-100	3	0	0	100	90	10	0	0.0
10	100-150	3	20	20	60	90	10	0	0.0
10	150-200	3	20	20	60	85	15	0	0.0
10	200-250	3	20	20	60	85	15	0	0.0
11	0-050	4	10	80	10	10	80	10	2.0
11	50-100	4	10	50	40	10	70	20	2.0
11	100-150	4	20	70	10	10	60	10	2.0
11	150-200	4	10	70	20	10	50	20	2.0
11	200-250	5	10	50	40	5	10	25	0.5

10.0 = poor, 1.0 = fair, 2.0 = good.
Table B.1. (cont.)

Site Number	50m Interval	Mean Channel Width (m)	Habitat Composition		Substrate Composition		Value for Spawning
			% pool	% riffle	% fines	% gravel	% bedrock
12	0-50	4	10	60	10	70	10
12	50-100	5	10	60	10	60	10
12	100-150	4	0	80	10	20	0
12	150-200	6	0	50	10	20	40
12	200-250	6	10	60	10	30	10
13	0-50	9	0	0	30	20	0
13	50-100	9	0	0	20	20	0
13	100-150	9	0	20	30	30	0
13	150-200	8	0	0	20	20	0
13	200-250	8	0	10	20	20	0

10.0 = poor, 1.0 = fair, 2.0 = good.
Table B.2. Biophysical characteristics for index sites in Trent River.

Site Number	50m Interval	Mean Channel Width (m)	Habitat Composition		Substrate Composition		Value ¹ for Spawning
			% pool	% riffle	% fines	% gravel	
1	0-100	30	0	0	30	40	0.0
1	100-200	30	0	0	30	40	0.0
2	0-100	25	15	20	10	25	1.0
2	100-200	20	20	20	10	15	0.5
3	0-100	35	20	45	10	30	1.5
3	100-200	25	0	10	15	35	2.0
4	0-100	25	5	80	15	35	2.0
4	100-200	40	20	50	10	25	1.0
5	0-100	13	25	60	15	15	0.0
5	100-200	20	10	75	15	35	1.5
6	0-100	21	10	60	10	30	1.0
6	100-200	27	5	70	10	20	0.5
7	0-100	16	5	85	5	15	0.0
7	100-200	17	35	50	15	20	0.5
8	0-100	27	5	70	10	15	0.5
8	100-200	19	0	90	5	10	0.0
9	0-100	16	20	70	10	20	0.0
9	100-200	16	10	25	10	20	0.5
10	0-100	18	15	70	10	10	0.0
10	100-200	17	40	30	10	10	0.0

10.0 = poor, 1.0 = fair, 2.0 = good.
Table B.3. Biophysical characteristics for index sites, excluding estuary site, in French Creek.

Site Number	50m Interval	Mean Channel Width (m)	Habitat Composition			Substrate Composition			Value for Spawning
			% pool	% riffle	% run	% fines	% gravel	% bedrock	
2	0-050	12	40	0	60	20	30	0	1.0
2	50-100	12	10	70	20	30	50	0	1.0
2	100-150	17	30	10	60	20	50	0	1.0
2	150-200	14	50	40	10	40	20	0	0.0
2	200-250	18	60	40	0	20	40	0	0.0
3	0-050	10	70	30	0	10	40	50	1.5
3	50-100	15	50	50	0	15	60	0	1.0
3	100-150	20	70	30	0	30	30	0	1.0
3	150-200	20	90	10	0	50	40	0	0.0
3	200-250	15	90	10	0	5	25	0	0.5
4	0-050	15	0	80	20	20	40	0	1.0
4	50-100	16	0	60	40	30	40	0	1.0
4	100-150	14	0	50	50	30	20	0	0.0
4	150-200	14	80	0	20	20	10	60	0.0
4	200-250	15	50	30	20	20	30	0	0.0
5	0-050	15	20	30	50	10	40	0	1.0
5	50-100	15	0	50	50	10	60	0	2.0
5	100-150	15	50	0	50	20	40	0	1.5
5	150-200	17	30	40	30	5	35	0	0.5
5	200-250	20	20	40	40	10	30	0	0.5
6	0-050	12	10	30	60	20	20	50	0.0
6	50-100	15	0	70	30	0	15	30	0.0
6	100-150	15	0	0	100	15	40	30	1.5
6	150-200	15	0	30	70	10	20	40	0.0
6	200-250	10	0	30	70	5	5	85	0.0

10.0 = poor, 1.0 = fair, 2.0 = good.
Table B.3. (cont.)

Site Number	50m Interval	Mean Channel Width (m)	Habitat Composition			Substrate Composition			Value for Spawning
			% pool	% riffle	% run	% fines	% gravel	% bedrock	
7	0-050	18	30	20	50	15	25	5	0.5
7	50-100	10	60	10	30	20	20	0	0.0
7	100-150	12	20	40	40	5	35	0	1.0
7	150-200	22	80	20	0	15	35	0	0.5
7	200-250	19	0	10	90	10	30	15	0.5
8	0-050	9	20	80	0	0	20	70	0.0
8	50-100	8	30	0	70	50	20	30	0.5
8	100-150	10	0	0	100	20	10	70	0.0
8	150-200	7	0	0	100	20	10	70	0.0
8	200-250	7	0	0	100	40	0	60	0.0
9	0-050	12	0	0	100	0	10	85	0.0
9	50-100	10	0	30	70	10	25	30	0.5
9	100-150	10	10	90	0	5	0	90	0.0
9	150-200	12	0	100	0	0	10	40	0.0
9	200-250	10	0	30	70	5	5	80	0.0
10	0-050	8	30	70	0	0	50	0	1.5
10	50-100	10	40	20	40	10	50	0	2.0
10	100-150	8	0	50	50	20	10	50	0.0
10	150-200	12	40	10	50	20	20	60	1.0
10	200-250	10	40	60	0	10	40	10	2.0
11	0-050	3	40	40	20	5	40	0	1.0
11	50-100	3	20	70	10	0	30	0	1.0
11	100-150	6	50	10	40	15	30	0	0.5
11	150-200	4	40	60	0	5	25	0	0.0
11	200-250	4	0	30	70	5	50	0	1.5

10.0 = poor, 1.0 = fair, 2.0 = good.

Table B.3. (cont.)

Site Number	50m Interval	Mean Channel Width (m)	Habitat Composition			Substrate Composition			Value for Spawning
			% pool	% riffle	% run	% fines	% gravel	% bedrock	
12	0-50	7	40	20	40	5	30	65	1.0
12	50-100	6	40	60	0	15	40	45	1.0
12	100-150	8	40	20	40	20	40	40	1.0
12	150-200	8	50	50	0	10	40	50	1.0
12	200-250	6	0	100	0	10	50	40	1.5
13	0-50	3	0	100	0	5	50	45	2.0
13	50-100	5	10	90	0	5	40	55	1.5
13	100-150	4	10	50	40	30	40	30	1.0
13	150-200	3	0	100	0	5	60	35	2.0
13	200-250	5	10	90	0	10	60	30	2.0
14	0-50	15	0	20	80	10	10	30	0.0
14	50-100	8	50	20	30	10	30	20	1.5
14	100-150	8	0	40	60	10	60	20	2.0
14	150-200	8	40	60	0	20	50	20	1.0
14	200-250	7	0	40	60	10	10	10	0.0

1.0 = poor, 1.0 = fair, 2.0 = good.

APPENDIX C

Count Data from Foot Surveys and Snorkel Surveys

Table C.1. Visual counts of live adult coho salmon (numbers/250 m unit) at index sites on Black Creek, 1987.

Stratum	Site	Nov. 23	Nov. 30	Dec. 5	Dec. 16	Dec. 19
A	I2	8	3	-	0	0
	I3	7	0	-	0	0
B	I13	0	0	-	0	0
C	I5	0	11	-	0	0
	I6	0	10	-	0	0
D	I4	0	21	-	0	0
	I7	0	10	14	0	0
	I8	0	0	3	0	0
E	I9	0	0	0	0	0
	I10	0	0	0	0	0
F	I11	0	0	17	6	0
	I12	0	0	4	0	0

Table C.2. Visual counts of live adult coho salmon (numbers/250 m unit) at random sites on Black Creek, 1987.

Stratum	Site	Nov. 23	Nov. 30	Dec. 5	Dec. 16	Dec. 19
A	R1	8	0	-	0	0
	R2	2	0	-	0	0
B	R3	0	0	-	0	0
	R4	0	-	-	-	0
C	R5	2	0	-	0	0
	R6	0	0	-	0	0
D	R7	0	0	3	0	0
	R8	0	5	0	0	0
E	R9	0	0	0	0	0
	R10	0	0	0	0	0
F	R11	0	0	3	8	0
	R12	0	0	32	0	0

Table C.3. Visual counts of live jack coho salmon (numbers/250 m unit) at index sites on Black Creek, 1987.

Stratum	Site	Nov. 23	Nov. 30	Dec. 5	Dec. 16	Dec. 19
A	I2	0	0	-	0	0
	I3	0	0	-	0	0
B	I13	0	0	-	0	0
C	I5	0	0	-	0	0
	I6	0	0	-	0	0
D	I4	0	5	-	0	0
	I7	0	2	7	0	0
	I8	0	0	1	0	0
E	I9	0	0	0	0	0
	I10	0	0	0	0	0
F	I11	0	0	6	0	0
	I12	0	0	0	0	0

Table C.4. Visual counts of live jack coho salmon (numbers/250 m unit) at random sites on Black Creek, 1987.

Stratum	Site	Nov. 23	Nov. 30	Dec. 5	Dec. 16	Dec. 19
A	R1	1	0	-	0	0
	R2	0	0	-	0	0
B	R3	0	0	-	0	0
	R4	1	0	-	0	0
C	R5	0	0	-	0	0
	R6	0	0	-	0	0
D	R7	0	0	1	0	0
	R8	0	3	0	0	0
E	R9	0	0	0	0	0
	R10	0	0	0	0	0
F	R11	0	0	0	0	0
	R12	0	0	4	0	0

Table C.5. Visual counts of live adult coho salmon (numbers/250 m unit) at index sites on French Creek, 1987.

Stratum	Site	Nov. 30	Dec. 13	Dec. 18
A	I2	0	0	0
	I3	0	1	0
B	I4	1	0	0
	I5	1	0	0
C	I6	1	1	0
	I7	0	0	0
D	I8	1	0	1
	I9	0	0	0
	I14	4	3	0
E	I10	0	0	0
	I12	0	0	0
F	I11	0	0	0
	I13	0	0	0

Table C.6. Visual counts of live adult coho salmon (number/250 m unit) at random sites on French Creek, 1987.

Stratum	Site	Nov. 30	Dec. 13	Dec. 18
A	R1	0	1	0
	R2	1	1	0
B	R3	0	0	0
	R4	0	1	0
C	R5	1	0	0
	R6	2	0	0
D	R7	0	0	0
	R8	4	3	0
E	R9	0	0	0
	R10	0	0	0
F	R11	0	0	0
	R12	0	0	0

Table C.7. Visual counts of live jack coho salmon (numbers/250 m unit) at index sites on Frech Creek, 1987.

Stratum	Site	Nov. 30	Dec. 13	Dec. 18
A	I2	0	0	0
	I3	0	0	0
B	I4	0	0	0
	I5	3	0	0
C	I6	1	0	0
	I7	1	0	0
D	I8	1	0	0
	I9	0	0	0
	I14	2	1	0
E	I10	0	0	0
	I12	0	0	0
F	I11	0	0	0
	I13	0	1	0

Table C.8. Visual counts of live jack coho salmon (numbers/250 m unit) at random sites on French Creek, 1987.

Stratum	Site	Nov. 30	Dec. 13	Dec. 18
A	R1	0	0	0
	R2	0	0	0
B	R3	0	0	0
	R4	2	0	0
C	R5	2	0	0
	R6	3	0	0
D	R7	0	0	0
	R8	2	1	0
E	R9	0	0	0
	R10	0	1	0
F	R11	0	0	0
	R12	0	0	0

Table C.9. Visual snorkel counts of live adult coho salmon (numbers/100 m unit) in the Trent River, 1987.

Stream Unit (m)	Nov. 18	Nov. 27	Dec. 13	Dec. 20
0	0	0	0	0
100	0	0	0	0
200	17	0	0	0
300	0	0	0	0
400	0	0	0	0
500	0	0	0	0
600	7	0	0	0
700	0	1	0	0
800	0	1	0	0
900	4	0	0	0
1000	4	0	0	0
1100	1	3	0	0
1200	7	1	0	0
1300	0	0	0	0
1400	8	0	0	0
1500	11	0	0	0
1600	0	0	0	0
1700	1	0	0	0
1800	0	0	0	0
1900	2	1	0	0
2000	0	0	0	0
2100	0	1	0	0
2200	0	0	0	0
2300	0	1	0	0
2400	0	0	0	0
2500	1	0	0	0
2600	0	1	0	0
2700	0	0	0	0
2800	0	0	0	0
2900	8	0	0	0
3000	0	0	0	0
3100	0	0	0	0
3200	0	0	0	0
3300	0	1	0	0
3400	0	0	0	0
3500	0	0	0	0
3600	0	1	0	0
3700	0	0	0	0
3800	0	0	0	0
3900	0	0	0	0
4000	0	0	0	0
4100	0	0	0	0
4200	0	0	0	0

continued . . .

Table C.9. (continued)

Stream Unit (m)	Nov. 18	Nov. 27	Dec. 13	Dec. 20
4300	2	1	0	0
4400	0	0	0	0
4500	19	0	0	0
4600	3	0	0	0
4700	1	1	0	0
4800	0	0	0	0
China Cr. ¹	0	16	0	0
4900	0	0	0	0
5000	0	0	0	1
5100	8	2	0	0
5200	0	1	0	0
5300	0	0	0	0
5400	0	2	0	0
5500	1	1	1	0
5600	0	1	0	0
5700	0	0	0	0
5800	0	0	0	0
5900	7	1	0	0
6000	0	4	0	0
6100	3	12	0	0
6200	4	3	0	3
6300	0	3	0	0
6400	0	0	0	0
6500	0	0	0	0
6600	47	3	0	0
6700	0	4	0	0
6800	0	2	1	0
6900	22	9	2	0
7000	24	2	3	0
Bloedel Cr. ²	0	6	0	0
7100	6	6	1	0
7200	0	0	1	0
7300	2	2	0	0
7400	3	8	0	0
7500	5	2	4	0
7600	0	0	0	0
7700	0	0	0	0
7800	0	0	0	0
7900	1	1	0	1
8000	0	1	0	1
8100	0	0	0	0
8200	0	4	2	0

¹The first 50 m of China Creek was surveyed.²The first 500 m of Bloedel Creek was surveyed, up to the falls.

Table C.10. Visual snorkel counts of live jack coho salmon (numbers/100 m unit) in the Trent River, 1987.

Stream Unit (m)	Nov. 18	Nov. 27	Dec. 13	Dec. 20
0	0	0	0	0
100	0	0	0	0
200	0	0	0	0
300	0	0	0	0
400	0	0	0	0
500	0	0	0	0
600	7	0	0	0
700	0	0	0	0
800	0	0	0	0
900	2	0	0	0
1000	3	0	0	0
1100	0	1	0	0
1200	0	0	0	0
1300	0	0	0	0
1400	3	0	0	0
1500	6	0	0	0
1600	0	0	0	0
1700	0	0	0	0
1800	0	0	0	0
1900	1	0	0	0
2000	0	0	0	0
2100	0	0	0	0
2200	0	0	0	0
2300	0	0	0	0
2400	0	0	0	0
2500	0	0	0	0
2600	0	0	0	0
2700	0	0	0	0
2800	0	0	0	0
2900	0	0	0	0
3000	0	0	0	0
3100	0	0	0	0
3200	0	0	0	0
3300	0	0	0	0
3400	1	0	0	0
3500	0	0	0	0
3600	0	0	0	0
3700	0	0	0	0
3800	0	0	0	0
3900	0	0	0	0
4000	0	0	0	0
4100	0	1	0	0
4200	0	0	1	0

continued . . .

Table C.10. (continued)

Stream Unit (m)	Nov. 18	Nov. 27	Dec. 13	Dec. 20
4300	0	0	0	0
4400	0	0	0	0
4500	7	0	0	0
4600	0	0	0	0
4700	0	0	0	0
4800	0	0	0	0
China Cr. ¹	0	3	0	0
4900	0	0	0	0
5000	0	0	0	0
5100	2	0	0	0
5200	0	1	0	0
5300	0	0	0	0
5400	0	0	0	0
5500	1	1	0	0
5600	0	0	0	0
5700	0	0	0	0
5800	0	0	0	0
5900	0	0	0	0
6000	0	0	0	0
6100	0	3	0	0
6200	1	0	0	0
6300	0	1	0	0
6400	0	0	0	0
6500	0	0	0	0
6600	10	0	0	0
6700	0	1	0	0
6800	0	0	0	0
6900	2	0	0	0
7000	2	1	0	0
Bloedel Cr. ²	0	1	0	0
7100	0	2	0	0
7200	0	0	0	0
7300	0	1	0	0
7400	0	2	0	0
7500	1	0	0	0
7600	0	0	0	0
7700	0	0	0	0
7800	0	0	0	0
7900	0	0	0	0
8000	0	0	0	0
8100	0	0	0	0
8200	0	0	0	0

¹The first 50 m of China Creek was surveyed.²The first 500 m of Bloedel Creek was surveyed, up to the falls.

APPENDIX D

**Results for Visual Foot Survey Efficiency
Tests for Black Creek and the Trent River**

Table D.1. Comparison of visual and electrofishing counts of adult coho salmon at Black Creek. All sites were 250 m in length.

Site	Habitat Type	Observer 1	Observer 2	Electrofisher
I5	Pool	0	0	1
	Riffle	7	8	8
	Run	7	2	14
I7	Pool	1	1	5
	Riffle	-	-	-
	Run	-	-	-
I11	Pool	3	4	6
	Riffle	3	3	3
	Run	2	1	2
I2	Pool	3	0	3 ¹
	Riffle	-	-	-
	Run	-	-	-

¹ corrected for approximately 30% efficiency of electrofisher in pools in stratum A which were generally much deeper than the upstream pools.

Table D.2. Comparison of visual and electrofishing counts of jack coho salmon in Black Creek. All sites were 250 m in length.

Site	Habitat Type	Observer 1	Observer 2	Electrofisher
I5	Pool	0	0	2
	Riffle	2	0	1
	Run	0	0	12
I7	Pool	2	1	3
	Riffle	-	-	-
	Run	-	-	-
I11	Pool	1	1	1
	Riffle	0	0	1
	Run	0	0	1
I2	Pool	0	0	3 ¹
	Riffle	-	-	-
	Run	-	-	-

¹ corrected for approximately 30% efficiency of electrofisher in pools in stratum A which were generally much deeper than the upstream pools.

Table D.3. Comparison of foot and float counts of adult coho salmon in the Trent River. All comparisons were made in pools in stratum D on 19 November.

	Observer on Foot				Float
Pool 1	2	7	0	6	7
Pool 2	8	6	6	8	11
Pool 3	1	3	3	-	40
Pool 4	11	16	18	-	31

APPENDIX E

**Abundance Histograms of Adult
Coho in Each Stream Derived Using
Population Mortality Model**

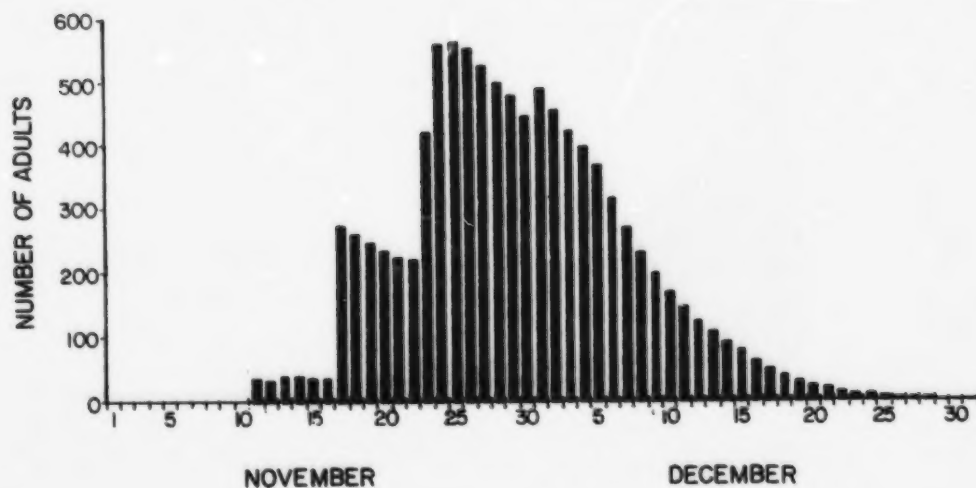


Fig. E.1 Histogram of abundance of adult coho in Black Creek derived from population mortality model incorporating fence counts and foot counts. Stream life was calculated to be 12.6 days by dividing the area under this curve by the mark-recapture estimate.

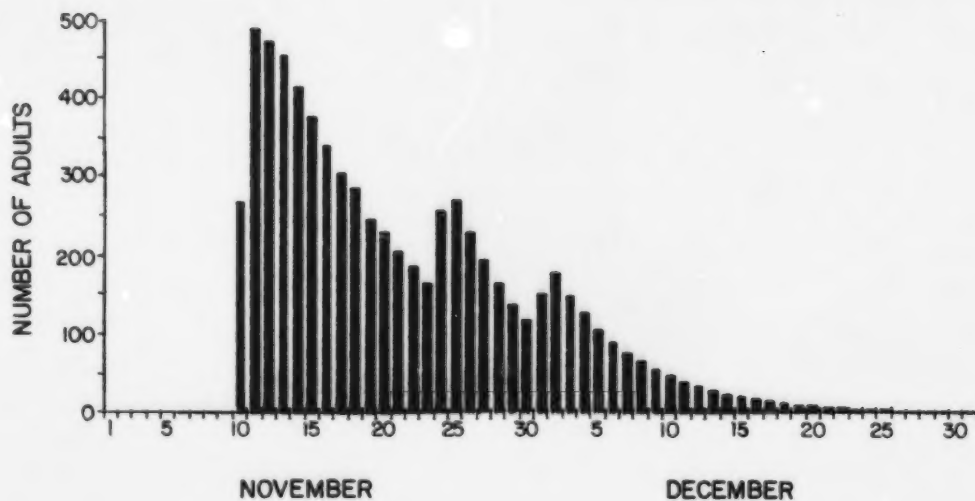


Fig. E.2 Histogram of abundance of adult coho in Trent River derived from population mortality model incorporating fence counts and foot counts. Stream life was calculated to be 7.8 days by dividing the area under this curve by the mark-recapture estimate.

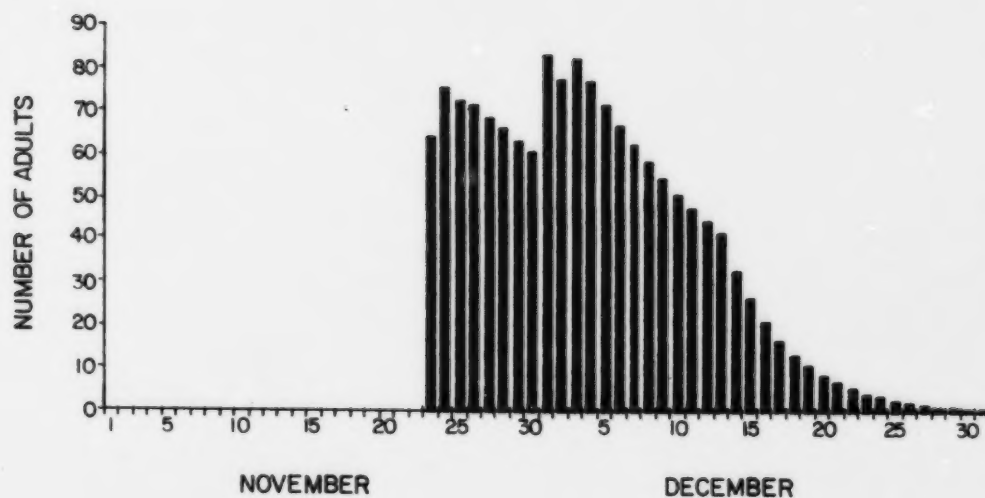


Fig. E.3 Histogram of abundance of adult coho in French Creek derived from population mortality model incorporating fence counts and foot counts. Stream life was calculated to be 13.3 days by dividing the area under this curve by the mark-recapture estimate.

APPENDIX F

**Visual Counts of Live Adult Coho Salmon
in French Creek, 1986-1987**

Table F.1. Visual counts of live adult coho salmon at French Creek, 1986. Counts (from Johnston et al. 1987) are corrected to numbers/250 m sample unit.

Index Site	Nov. 20	Nov. 25	Dec. 3	Dec. 10	Dec. 16	Jan. 6
2	0	0	0	0	0	0
3	0	0	1	0	0	0
6	1	1	2	2	1	0
7	0	5	8	14	0	0
8	3	1	1	4	1	0
10	0	1	3	2	1	0
11	0	2	7	3	0	0
13	1	1	0	1	0	1

Table F.2. Visual counts of live adult coho salmon (numbers/250 m unit) at French Creek, 1987. Bold numbered sites are those used for comparisons with 1986 data.

Index Site	Nov. 30	Dec. 13	Dec. 18
2	0	0	0
3	0	1	0
4	1	0	0
5	1	0	0
6	1	1	0
7	0	0	0
8	1	0	1
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	0	0	0
14	4	3	0